MINISTRY OF HOUSING AND LOCAL GOVERNMENT

Pollution of Water by Tipped Refuse

Report of the Technical Committee on the Experimental Disposal of House Refuse in Wet and Dry Pits

LONDON
HER MAJESTY'S STATIONERY OFFICE
1961

The Technical Committee on the Experimental Disposal of House Refuse in Wet and Dry Pits was appointed by the Minister of Housing and Local Government on the 10th June, 1953, with the following terms of reference:

> "To define and generally guide experiments to be carried out at the Bushey Urban District Council's old sewage works on the tipping of household refuse of various categories under dry and wet conditions of deposit, with special reference to the pollution of underground water;
>
> to report on the results of the experiments; and
>
> to make recommendations as to their practical application".

Members of the Committee:

A. Key, D.Sc., Ph.D., F.Inst.S.P. (*Chairman*).

Lieut.-Colonel F. G. Hill, C.B.E., M.C., M.I.C.E. (*Chairman—retired* 1955).

J. L. Dunlop, M.D., D.P.H. (*from* 1954).

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We have carried out experiments designed to give information about the risk of polluting ground water by tipping house refuse (*a*) where percolate from it has access to that water and (*b*) direct into water communicating with ground water.

The matter has proved exceedingly complex and it is quite impossible to prepare a short technical summary of our conclusions which would be useful and not at the same time liable to be misleading. It is essential that anyone wishing to use our results should read the whole report.

The experiments carried out included a number on a small scale and two on a much larger one, all under as strict scientific control as possible. They also included experiments on the purification by filtration through gravel and sand of water contaminated by having been in contact with tipped refuse.

One larger scale experiment was on refuse tipped dry and the other on refuse tipped into water. In the former case the whole of the percolate was collected, measured and analysed over a period of 2½ years, at the end of which time it contained little polluting matter. In the latter case the water leaving the tank into which tipping had been carried out was controlled, measured and analysed for about 18 months. The filtration experiments covered about a year.

We have measured the amount of pollution in rainfall after percolating through a controlled tip and found it considerable. We have also shown that the liquid undergoes purification during its subsequent passage through sand and gravel. It seems important to emphasise here that, overall, our work constitutes no condemnation of controlled tipping. It is generally a satisfactory method of refuse disposal and there is no reason why it should not continue to be widely used. We now have more fundamental knowledge which should be of value in the selection of satisfactory sites. Indeed, as a result of our work it may now be possible, with appropriate safeguards, to bring into use sites hitherto considered unsuitable.

Similarly, we have measured the pollution arising through tipping refuse into water under controlled conditions. Here again, the fact that it is considerable does not mean that such tipping would always constitute a danger to underground water supplies. We believe that it should be possible to use the information we have collected to get a better idea than was formerly possible of the risks which may be attached to the use of any particular sites.

We believe the question of pollution should be pursued. The next step would appear to be to collect information, which, as we explain, might easily be obtainable, relating to existing conditions, and to consider it in the light of our findings. It is likely that this will point the way to further full-scale study, probably in co-operation with some local authorities and water undertakings. Because of the difficulties confronting many local authorities in the matter of sites for refuse disposal, the need for reclamation of certain sites, and the necessity of protecting ground water against pollution, we strongly recommend that the whole matter should be the subject of further work.

Experiments on Polluted Liquids arising from Tipping of House Refuse

Report of Technical Committee

INTRODUCTION

1. We were appointed by the Minister of Housing and Local Government to make arrangements for, and exercise a general oversight over, certain experiments which it had been recommended should be made on the tipping of house refuse. These have now been completed and are fully described in the detailed Report which follows our own, by members of the staff of the Department of Scientific and Industrial Research, the Laboratory of the Government Chemist, who have been in immediate charge of the work and have carried out all the analyses. We have studied the results and discussed them and their application to practice. We feel that it would be far more helpful to state the conclusions, deductions and suggestions, however speculative, which can now be made as a result of our experiments, rather than confine our report to the factual results we have obtained. We are very conscious that we cannot yet assess, in any quantitative way, the effect of the many variable conditions that occur in actual practice and which it has not yet been possible to study under controlled conditions. Our experiments have indicated possibilities which have not been established beyond doubt, but which would, we think, well repay further investigation. The report should therefore in no way be considered as an infallible guide to future practice, but rather a helpful addition to knowledge on the subject giving also an indication of the lines along which further experiments could be carried out.

REASONS FOR THE EXPERIMENTS

2. The greater part of the house refuse of the country is disposed of either by controlled tipping or by separation-incineration, often combined with the salvaging of waste paper, metals and other materials of value. Separation-incineration is expensive and a not inconsiderable proportion of refuse so dealt with remains for disposal after treatment; usually it must be tipped. Controlled tipping is satisfactory and generally less costly. Its adoption, however, wholly depends on the availability of suitable sites, which in some areas are becoming increasingly difficult to find, particularly within 30 miles of London. Sites involving long hauls are more expensive to use and the use of good agricultural land is undesirable. The magnitude of the problem can be gauged from the fact that the amount of house refuse (including, however, refuse from some traders) collected for disposal in England and Wales is approximately 11 million tons per annum.

3. There are, however, worked-out chalk pits in the counties of Hertfordshire, Kent and Surrey, and there are disused gravel pits, usually waterlogged, in the Thames Valley, Hertfordshire and Essex; most of these need filling and the land reclaiming for a useful purpose. In other parts of the country there are numerous similar excavations and quarries, including ironstone workings, most of which require similar treatment. If house refuse could be used for this purpose it would be doubly advantageous.

4. Hitherto it has been considered undesirable to tip house refuse on to a bare chalk formation or other fissured water-bearing strata because of the risk of polluting ground water. Tipping direct into water has also been considered undesirable; here, in addition to the risk of pollution of ground water, there is that of aerial nuisance. Although a good deal has been discovered about the magnitude of aerial pollution, little was known about the risk to ground water or whether it could be minimised or eliminated by suitable precautions in disposal.

5. It seemed urgently necessary that such information should be obtained. Large-scale trials under practical conditions clearly provided the best means of assessing the possibilities of methods of eliminating aerial pollution, and trials to this end have been carried out (not by us) at Egham, Surrey.* We have not considered this aspect of the matter. These trials have also given information on pollution of ground water, but for this any large-scale trial has serious disadvantages including:

(1) Ground water would actually be exposed to the risk of pollution and this might have serious consequences.

(2) The results might be so influenced by local conditions as to be inapplicable generally.

(3) Important factors such as the rate and direction of flow of water through the refuse and underground might be unknown.

(4) Not all the relevant factors could be brought under scientific control.

6. There is obviously an important place for large-scale trials, but it was felt that it might be possible to obtain some fundamental information from controlled experiments in which these disadvantages could be eliminated and a Working Party was set up to consider how this could be done. In its report this Working Party recommended that a series of experiments should be carried out at an old and disused sewage treatment plant at Bushey in Hertfordshire, using the tanks to contain the refuse. The experiments should include both dry and wet tipping and different types of refuse. The recommendation was accepted and this Technical Committee was set up in June, 1953, to make the arrangements, to exercise a general oversight over the work and to consider the results. It was arranged that the experiments themselves should be carried out by the Laboratory of the Government Chemist under the direction of Dr. J. Longwell.

7. It was not expected that the work would provide answers to all the questions. Few research projects ever do. Nor was it expected that the results could be applied to individual cases without careful thought and perhaps further local investigation; the geology of the area must always be an important factor. But it was hoped that reliable information would be gained on the quantity and

* Chapter 1 of the accompanying detailed Report on the experiments, which comprises a survey of the literature, contains a reference to work carried out at Egham.

composition of polluting liquids to which tipped house refuse gives rise and on the rate of removal of polluting matter when the effluents are allowed to percolate through media of various kinds under different conditions. These hopes have been broadly realised and the information is given in the detailed Report which follows this one. This Report summarises the factual observations and contains our assessment of their meaning in practice. It is believed that, now that some fundamental information has been secured, observations in the field will be all the more valuable, and we think they should be made. Now that we know what to look for, it seems probable that conditions already exist in various parts of the country which would provide most useful information. In selected cases it may be possible to create these conditions and solve a refuse disposal problem at the same time, without any appreciable risk to water supplies.

EXPERIMENTS WITH REFUSE TIPPED UNDER DRY CONDITIONS

PRELIMINARY SMALL-SCALE EXPERIMENTS

8. It was agreed that laboratory scale experiments would not give the desired information, partly because a fairly large bulk of refuse is necessary to obtain a representative sample and partly because self-heating of the refuse cannot be expected to occur in only a small amount of refuse. It was thought that the chemical changes occurring while the refuse was hot might profoundly modify the character of the water percolating through it into the ground. Nevertheless it was believed that, while the necessary facilities were being provided at Bushey, it would be well worth while to conduct some small-scale experiments. They would at least give some idea what to expect and prepare for on the larger scale, and might give guidance on the conduct of the large-scale test.

9. The experiments, referred to later as the "Pipe" experiments (see pages 42 to 52)*, were all carried out in vertical drainpipe assemblies 6 ft. long and 1 ft. in diameter, the refuse (from Watford) being supported on 3 ins. of gravel and covered after compaction with a few inches of soil. Rain was applied either naturally or artificially as distilled water and the percolate was measured and examined. Records were kept of rainfall, humidity, and air and refuse temperatures. There was no evidence of the refuse heating up under these conditions.

10. House refuse as tipped has a capacity for absorbing water, and until it becomes saturated no water drains away. The general conclusion of the pipe experiments was that a 6-ft. depth of refuse did not begin to produce a percolate until about 8 to 10 ins. of rain had fallen and that this value did not vary much with the rate of rainfall. Once the refuse was saturated, rainfall was almost immediately followed by the appearance of a percolate, but the volume of the percolate naturally varied with the season of the year. It was perhaps unfortunate in these experiments that the winter and spring, when percolation would be expected to be great, were dry, whereas the following summer, the season of little expected percolation, was exceptionally wet.

* References to pages and tables refer to the detailed Report of the experiments; references to paragraphs to the Committee's Report.

11. In the experiment deliberately conducted so that percolation began within a week or so of the start, the percolate was an extremely polluting liquid. Its B.O.D. and content of carbonaceous matter were some thirty times as great as those of an average crude sewage, but the content of nitrogenous matter was relatively much smaller, owing no doubt to the vegetable nature of the organic content of house refuse. After about six months the strength of the percolate fell sharply and thereafter more slowly, until after a year the strength was of the same order as that of a well purified sewage effluent.

12. In the experiment with natural rainfall, where no percolate appeared for five months, its initial quality was much better than that appearing first in the other experiments. It was indeed about the same as those percolates were after five months. It is to be noted, however, that in these experiments it could not be guaranteed that the base of the refuse was maintained anaerobic, as it would be normally in practice. The significance of this is discussed later (see paragraph 98 *et seq.*).

13. As will be seen from the detailed Report, a great deal of information was obtained about the organic nature of the percolates and also about inorganic contaminants and the bacterial content. This also will be referred to later.

DRY TANK EXPERIMENT AT BUSHEY

14. It has unfortunately been possible to carry out only one large-scale experiment (referred to later as the "Dry Tank" experiment) on the dry tipping of refuse, but this was followed in great detail and in our view has given most useful information. It is described in full in the detailed Report (pages 53 to 81). It was designed to secure accurate measurements of the quantity and quality of any percolate resulting from the controlled tipping of house refuse in such a manner as to simulate as far as possible normal practice. At the same time rainfall and humidity measurements were taken, together with temperature measurements at a number of selected points within the tipped refuse. The refuse was kept under observation for 2½ years.

15. The refuse was tipped into a rectangular tank 42 ft. × 35 ft. of an average total depth of 6¾ ft. Details of the arrangements for collecting the percolate are given on page 53. To facilitate rapid drainage of the percolate to the outlet a 9-in. layer of 3-in. to 6-in. clinker was first placed in the tank. Then refuse was added as quickly as possible in the circumstances, the process taking about a fortnight, during which very little rain fell. In all about 90 tons were used and it was compacted by a mechanical vibrating roller to a depth of approximately 5 ft. and a density of 6·6 cwts. per cubic yard. The final cover was 18 ins. of soil from an adjacent field. Although at one time this field had been used for sewage sludge disposal it is not thought that the results have been adversely affected.

16. The refuse was entirely domestic and had not been subject to any sorting or salvage. No separate waste food collection scheme was in operation at the time. An analysis is given on page 54, from which it will be seen that it was a typical summer domestic refuse, having a high content of paper and vegetable matter and a relatively low content of cinders and fine ash. As far as was known substantial quantities of putrescible animal matter were not present.

17. By the time the covering had been placed in position, the temperature within the body of the refuse was already close to 160°F. In addition, there was an almost immediate appearance of a small quantity of water attributable to the "sweating" of the refuse within the tip. Compared with the true percolate which appeared later it can be neglected entirely.

VOLUME OF PERCOLATE

18. The amount of rain which had fallen on the 5-ft. depth of refuse plus 1½-ft. covering before the amount of percolate became significant and related to the rainfall in a normal manner was about 7·3-ins., which agrees fairly well with the figure of 8·4-ins. obtained for a 6-ft. depth in the pipe experiment under natural rainfall.

19. Immediately after the refuse was saturated the amount of percolate followed a recognisable pattern. Firstly, it was related to the rainfall: it is clear from Table V, page 57, that the greatest amount of percolate occurred in those months with the highest rainfall, though occasionally they occurred in the month following a month of high rainfall. It appears that a period of heavy rainfall began to affect the quantity of percolate almost immediately but that the effect continued for a further month or so. Secondly, the proportion of percolate to rainfall was related to the period of the year; percolation was greatest in the winter. This is as would be expected, but it is to be noted that even in the summer time there was some small amount of percolation: on the other hand percolation was less than 100 per cent of the rainfall in the winter. So far as could be seen there was no possibility of loss of rainfall by run-off, so that an appreciable amount of evaporation and transpiration must have occurred even in the coldest months, assisted perhaps by the fact that the temperature within the body of the refuse was even then considerably higher than that of normal soil in winter. It should be mentioned that the surface of the tip rapidly became covered with a rank growth of grass and weeds which were kept down by periodically using a sickle. The surface was never waterlogged.

20. Assuming that all the rainfall either appeared as percolate or was lost by evaporation and transpiration, the following table gives the overall results for two years:

Period	Rainfall (ins.)	Percolate (ins.)	Evaporate and Transpirate (ins.)
January, 1955, to December, 1955 ..	22·3	8·73	13·57
January, 1956, to December, 1956 ..	27·09	11·62	15·47

These figures for evaporation and transpiration are appreciably lower than the figure of about 18-ins. annually which has been stated to be normal for this part of England.

21. It seems certain that when a normal house refuse is tipped in 6-ft. layers no significant percolate will occur for at least several weeks. We think this important. During part of this time most of the refuse will have been subjected to temperatures which, if not actually lethal, are most unfavourable to the reproduction of pathogenic organisms. Even where not so subjected the environment can hardly have favoured their multiplication and we expect that there would have been a marked tendency for them to die off under the stress

of competition. To what extent pathogens are likely to be present in house refuse does not seem to be known, but there seems no doubt that the delay in percolation greatly reduces the chance of any eventually being carried in a viable condition to ground water.

22. The length of the interval between tipping and the production of a percolate no doubt depends primarily on the rainfall, but the rate of evaporation must also be important and perhaps the composition and the degree of consolidation of the refuse. All our experiments have, however, given about 1·3-ins. to 1·5-ins. per foot depth as the amount of rain necessary to produce the first percolate and we think this figure can be taken as a rough working guide irrespective of other conditions. It could, however, be seriously in error in abnormally dry weather or when conditions (e.g., good consolidation combined with an effective surface gradient) are such that there is a substantial run-off of rain from the surface of the tip.

23. A figure of 1·3-ins. to 1·5-ins. of rain per foot depth means that in the drier parts of the country (25-ins. rainfall per annum) an average of 3 to 4 months elapses between the tipping of a 6-ft. layer and the appearance of a percolate from it. Where it is possible for several 6-ft. layers to be tipped successively it may well be that, if layers could be added at 3- to 4-monthly intervals, no significant drainage would occur until several months after the tipping of the final layer. This, however, has not yet been proved.

24. After percolation had been fully established, it continued at a rate corresponding to about 10-ins. per year under a rainfall of about 25-ins. per year. This is some 3 or 4-ins. greater than would be expected through normal pervious land (with no run-off) in the same district and with the same rainfall. It is not certain what was the cause of this, which must have been accompanied, in the absence of any other source of water, by a lower than normal amount of evapo-transpiration, of which there was no independent evidence. We can only suggest that at present, for purposes of calculating volumes of percolate, it would be safer to assume it to be 3 or 4-ins. more than is normally the case with permeable soils in the same area.

25. With a rainfall of about 25-ins. per annum, the annual amount of percolate at Bushey was about 10-ins., about 90 galls. per ton of refuse tipped 5-ft. deep and about 45-galls. per sq. yd. of tip.

26. No means were available for measuring the permeability of the tipped refuse, but it was found that similar refuse tipped into water had, after some months, a permeability about equal to that of medium sand. It seems likely that in practice the permeability would be smaller, because of extra compaction with bulldozers and by the passage of lorries, etc. No doubt permeability has some influence on the volume of percolate, but it seems to us that the major effects will occur only when the refuse is so compressed and the surface is given a significant gradient so that there is an appreciable run-off of rainfall. This will reduce the amount of percolate, particularly at times when it would normally be at its maximum, and correspondingly reduce the danger of contamination of ground water.

27. Attention is also drawn to the observation that heavy rainfall causes an increase in the volume of percolate over days and probably weeks. The refuse has a balancing effect on the flow of water downwards. We have no data to compare this with the balancing effect of ordinary permeable ground, but it

seems reasonable to conclude that there will not be flushes of water reaching the water table from the tipped refuse except at times when similar flushes are reaching it from the ground in the surrounding area.

BACTERIOLOGICAL QUALITY OF THE PERCOLATE

28. In the bacteriological examination of water intended as a source of public supply, standard methods are normally used to determine the number of coliform organisms, of *E. coli.* and, where necessary, of faecal streptococci present. These methods prove satisfactory because the number of organisms is not normally very large and other organisms which might be mistaken for those mentioned are usually absent. It did not follow that these standard methods would be equally satisfactory in the examination of the percolate from such an unusual medium as house refuse. In fact great difficulties in accurately determining numbers of bacteria were experienced, difficulties which varied as the experiment progressed. A full account of these is given on pages 72 to 73 where the results are recorded. It does not seem to be possible to say more than that when percolation became first established very large numbers, of the order of 1,000,000 per ml., of potentially harmful bacteria* were present in the percolates. They tended to be higher at periods of maximum percolation, but overall there was a steep downward tendency with time, so that after one year *E. coli.* and faecal streptococci were reduced to about one or less per ml. whilst after two years they were absent.

29. It is plain that, if fresh house refuse were so tipped that its first percolate quickly reached, without effective filtration, ground water pumped for supply, that water would become dangerously contaminated. On the other hand percolate leaving the refuse after one year would be unlikely to result in serious bacterial contamination.

POLLUTING MATTER IN THE PERCOLATE

30. Although the presence of potentially harmful bacteria in water intended for drinking is of course directly far more dangerous than the presence of organic matter as such, the latter can at times give rise to greater difficulty. It is largely for this reason that the quality of a sewage effluent discharged to a river used as a source of public water supply is judged by its organic content and not on its bacteriological condition. In view of the complexity of the matter it will be necessary to discuss the organic constituents of the percolate from the dry tank in far greater detail than the bacterial content.

31. It may be said immediately that the percolate during the first year of its production was organically very highly polluting indeed, being twenty or thirty times as strong as a settled sewage. Generally the relative concentrations of the different types of contamination revealed by normal analysis were very similar to those in a settled sewage which has been allowed to become septic. During the second year the percolate became progressively and rapidly weaker and it is expected that this tendency would have been maintained had the experiment been continued.

* The expression "potentially harmful bacteria" in this context means bacteria whose presence indicates the possibility that pathogenic organisms might also be present. Whether pathogenic organisms were, or ever are, present in percolate from refuse we cannot say. But water containing the indicator organisms derived from it would quite properly be condemned on bacteriological grounds.

Biochemical Oxygen Demand

32. This figure represents the amount of oxygen utilised in biological oxidation in five days under standard conditions and provides a useful indication of the amount of readily oxidisable organic matter in a polluting liquid. That of an average domestic sewage is about 400 p.p.m. That of the percolate averaged over 6,000 p.p.m. during the first winter (November to February). Thereafter it diminished rapidly, reaching a value of less than 50 p.p.m. in two years.

33. The concentration of B.O.D. tended to be greater in the winter when the volume of percolate was also greater. In the following table the total weight of B.O.D. draining during successive periods is given:

Period	B.O.D. draining (kg.)
June, 1954, to June, 1955 (51 weeks) ..	167
June, 1955, to October, 1955 (20 weeks) ..	7
October, 1955, to March, 1956 (20 weeks) ..	28
March, 1956, to October, 1956 (30 weeks) ..	0·4
October, 1956, to February, 1957 (20 weeks)	0·9
TOTAL ..	203·3

It will be seen that during the final year of the experiment the total amount of B.O.D. in the percolate was only 0·5 per cent of that draining previously. It seems certain that any subsequent extraction would have been quite negligible. No less than 82 per cent of the whole appeared in the first year's percolate.

34. The total B.O.D. in the percolate during nearly three years was 203·3 kgs. Assuming 5 cwts. of domestic refuse per person per year, the tip contained the equivalent of a year's refuse from 360 people, from which it can be calculated that the total B.O.D. drainage from the refuse from one person per year was 0·56 kg.

Permanganate Value and Organic Carbon

35. These measure, respectively, the content of organic matter susceptible to chemical oxidation by permanganate, and the total organic carbon, whether biologically oxidisable or not.

36. Their concentration in the initial percolate was high, broadly commensurate with the B.O.D., and later fell progressively, though not so rapidly as the B.O.D. The rate of decline is illustrated in the following table which records the total weights draining in successive periods:

Period		Organic Carbon kg.	Permanganate Value kg.
1st year	June, 1954, to June, 1955 ..	96	19
2nd summer	June, 1955, to October, 1955 ..	6	2
2nd winter	October, 1955, to March, 1956	23	6
3rd summer	March, 1956, to October, 1956	4	2
3rd winter	October, 1956, to February, 1957	5	2
TOTAL ..		134	31

37. It will be seen that, broadly speaking, the amount of organic carbon extracted diminished by about two-thirds each year, and the amount of permanganate value by a little less than this. The inference is that the amount draining in subsequent years would have been by comparison negligible in each case. Much more than half occurred in the first year.

38. On pages 75 to 77 figures are given indicating the relationship between the organic carbon and permanganate value (as oxygen) extracted in the two years and that originally present in the refuse which was and was not extractable with water. The figures can only be very rough, but it is quite plain that only a proportion of the original extractable carbon and a very small proportion indeed of the total carbonaceous matter, had appeared in the percolate within two years. This was not unexpected. Some of the carbon was originally in a stable insoluble form (coke and cinder), some was oxidised in the initial stages (while the refuse was heating up), some may have been decomposed to methane and carbon dioxide by anaerobic fermentation later (in the treatment of some organic trade wastes by this process the greater portion of the carbon is lost), and some had no doubt been converted into relatively stable humus. It seems to us that there is no more reason to expect further drainage of soluble organic carbon from stabilised refuse than from a normal fertile soil containing humus.

39. It should be mentioned that the organic carbon discharged in the later stages of the test was resistant to biological oxidation, as indicated by the low B.O.D. of the percolates. It was probably of similar composition and properties to that of organic matter extracted by water draining through, say, peat.

Ammoniacal and Organic Nitrogen

40. These varied similarly and can be considered together. The maximum concentration of ammoniacal nitrogen was about 700 p.p.m., and this fell to about 40 p.p.m. at the end of the experiment. The following table shows the total weight drained in successive periods:

Period	Ammoniacal Nitrogen kg.	Organic Nitrogen kg.
June, 1954, to June, 1955 (51 weeks) ..	16·2	3·6
June, 1955, to October, 1955 (20 weeks) ..	2·2	0·4
October, 1955, to March, 1956 (20 weeks) ..	7·9	1·1
March, 1956, to October, 1956 (30 weeks) ..	2·9	0·4
October, 1956, to February, 1957 (20 weeks)	1·6	0·4
TOTAL ..	30·8	5·9

41. It is clear the extraction of nitrogen compounds was rapidly approaching completion at the end of the experiment. The fall in concentration was particularly rapid in the third winter and again the inference is that little contamination would be contained in drainage in subsequent years.

Oxidised Nitrogen

42. Although on page 64 appreciable quantities of oxidised nitrogen were recorded as having been present in the very small amount of water produced by the "sweating" of the refuse, no appreciable amount was ever present in the normal percolate. We refer later to the sharp contrast between this experiment and the pipe experiments in this connexion (see paragraph 98, *et seq.*).

Sulphate and Sulphide

43. Throughout the period of observation sulphide was present in the percolate. Concentrations were not great, ranging from 2 to 29 p.p.m., and they tended to fall with time. The sulphide no doubt arose mainly from the reduction of sulphate, a matter which was confirmed by the detection of sulphate-reducing bacteria in the percolate. As refuse becomes more and more stabilised its rate of oxygen demand must fall and no doubt in time would be satisfied by the oxygen carried into the body of the tip by rain and by diffusion. Ultimately, therefore, sulphide would be expected to disappear from the percolate; it was already down to 2 p.p.m. after two years.

44. Sulphate in the percolate must arise principally from soluble sulphate in the ash in the refuse, although eventually, when oxidation is the principle reaction occurring in the tip, some sulphate from organic sulphur might be expected. Throughout our observations, however, the refuse remained in an anaerobic condition. The concentration in the percolate varied very widely, from 2 to 1,800 p.p.m., with no very definite pattern. In general it was lower in the summer and higher in the winter, but the lowest concentration of all occurred in the first and not the second summer and the greatest occurred in the second and not the first winter. There was no indication of a general reduction with time and it is certain that by no means all the sulphate had been leached out in 2½ years. At the end of the experiment, however, the top layer of refuse contained less than one quarter as much of extractable sulphate as the bottom layer. During the whole experiment 68·6 kgs. of sulphate (as SO_4) (or 0·78 kg. per ton of refuse) appeared in the percolate. Unfortunately no determination of extractable sulphate had been made on the original refuse. A sample taken in January, 1956, of fresh refuse from the same area of Watford gave a figure of 4·94 kgs. per ton. If the same figure applied in the case of the refuse in the dry tank, it would appear that only 16 per cent had been leached out, but the summer refuse in the dry tank might not have contained so much originally.

45. Although a proportion, probably a large proportion, of the sulphate will, while conditions are anaerobic, be reduced to sulphide and fixed in an insoluble form, it may be that ultimately it will be re-oxidised in sulphate. In preliminary calculations, until further information is forthcoming, it would therefore be wise to assume that all sulphate in refuse which is extractable by water will in the long run be washed out, and that this may take at least several years. Its subsequent behaviour in the ground is also uncertain (see paragraph 117, *et seq.*).

Chloride

46. Chloride was not estimated in the initial samples of percolate but when a determination was carried out after eight months the figure was surprisingly large and it was thereafter obtained as part of the routine. Compared with the other constituents it varied only slightly and haphazardly, and although there was a downward trend it was at first only a slow one, e.g., May to July, 1955, 1,700 p.p.m. and May to July, 1956, 1,525 p.p.m. After this, however, it fell more quickly, and in the following winter it averaged only 800 p.p.m. and in the final month it was only 573 p.p.m. Water extraction of the refuse at the end of the experiment gave only small quantities of chloride, from which it may be assumed that the rapid fall in concentration in the percolate which had just begun would have continued had the experiment been prolonged and that the tip would have been substantially free from chloride after little more than three years.

47. The soluble chloride content of crude refuse was almost the same in the winter and summer samples analysed (see page 110); it amounted to 0·9 kg. per ton.

GENERAL DISCUSSION ON THE CONTAMINANTS OF THE PERCOLATE

48. For this purpose the contaminants can conveniently be divided into the following classes:

(1) *Bacteria*, which can be removed by filtration, for example in suitable subsoil.

(2) *Organic matter, and ammonia*, which cannot be removed by any mechanical process. Generally, we would look to biological processes to remove these contaminants, and in the case of ammonia it would have to be biological oxidation. Ammonia, however, could be removed by base-exchange reactions under certain conditions.

(3) *Inorganic salts*, which would normally not be removed from an effluent by any biochemical or chemical process to which it would always be exposed under natural conditions.

49. Any of these types of contamination may be sufficient to make a water unfit for public supply and some other purposes as well. The danger due to bacteria needs no elaboration, and it is quite plain from the results already described that crude refuse should not be tipped where percolate from it can pass direct to an underground source of water supply without being effectively filtered. What might be an effective filter will be discussed later in this report (see paragraph 68, *et seq.*).

50. Organic matter and ammonia are not dangerous because of any specific toxicity they possess though it is possible that some particular compound may be directly harmful—this has not been proved either way. Their presence may give colour, turbidity, taste or odour to the water and, particularly in the case of ammonia, prevent treatment by chlorination from being effective. It is a good principle, which we wish to see upheld, to regard any underground water intended for public supply as suspect which contains more than minimal amounts of organic matter and ammonia. We are quite sure that a water chemist would condemn out of hand for drinking purposes water which contained as little as 1 per cent of the concentration of the organic matter and ammonia found in the percolate at Bushey over the two years of the test. It is obvious, therefore, that tipping of crude refuse should take place only under conditions where purification and dilution can be relied on to reduce almost to vanishing point the concentration of organic matter and ammonia in the ground water at the point where it is withdrawn for use. The question of purification is discussed later in this report (see paragraph 68, *et seq*).

51. Of the mineral constituents present in the percolate, sulphate and chloride occurred in such concentrations that, on their account alone, the percolate without dilution would be judged quite unsuitable for a water supply. We do not believe that chloride is normally removed from water as it travels underground. There are certain indications that sulphate may be, on occasions, destroyed or retained in the ground, but much more evidence is required on the subject and, for the purposes of this section, it is assumed that the only factor available to reduce the concentration of both chloride and sulphate is

dilution with uncontaminated water. A simple calculation then suffices to determine the amount of diluting water necessary to achieve reduction of the concentrations to any given level. It is not, however, possible to lay down precise figures for either chloride or sulphate above which a water is unfit for supply or any other purpose. Excessive concentrations of sulphate can make a water unacceptable on health grounds. Any increase in sulphate, if present, as it probably is, as calcium sulphate, increases the hardness of water and makes it correspondingly less acceptable for both domestic and certain industrial uses. Chloride may make the water more corrosive to metals and excess may cause a saline taste. Any increase in the natural concentration of either chloride or sulphate would be looked upon with disfavour, but small increases might be acceptable as the price to be paid for a convenient means of refuse disposal.

52. On the assumption that natural percolation is 6-ins. per annum and percolate through refuse 10-ins. per annum, an estimate may be made of the area of gathering ground required for each acre of refuse tip 5 ft. deep to effect dilution of the sulphate and chloride concentrations to predetermined levels. To dilute percolate of a quality the average of that found over two years at Bushey to a concentration of 20 p.p.m., would, in the case of sulphate, require the natural percolation (as assumed above) from 60 acres of land (but see paragraph 117, *et seq.*); for chloride 100 acres would be necessary. The latter figure takes into account the further assumption that the chloride concentration during the period when no measurements were made was equal to the average of the figures found subsequently. Because of the more rapid extraction of chloride, it would be permissible on that account to make a further tip on a catchment area after three years. The period required for sulphate, however, might be much longer. The method of estimation ignores water already in the ground which would be available to provide additional dilution.

53. The above has been given merely to illustrate the type of estimate which could usefully be made to assist in assessing the possible effect of refuse tipping in a particular case. It must not be supposed that the figures of 20 p.p.m. indicate our view of what might be permissible. This depends on circumstances.

54. If the ammonia in the percolate is subsequently oxidised to nitrate then nitrate must also be considered as being in the class of contaminants the concentration of which can only be reduced by dilution. Nitrate in public water supplies, if present in excess, can be very harmful to young children and, working from the figures for ammoniacal nitrogen, it seems that the degree of dilution required for the percolate would be of the same order as that estimated above for chloride and sulphate. The removal of ammonia underground, however, is discussed later (see paragraph 75, *et seq.*).

55. The work described so far was designed to measure and analyse the percolate from domestic refuse when tipped in the way normal to controlled tipping. In particular we had in mind the tipping of refuse on to chalk or other formation which might be fissured and allow percolate to descend to the water table without being filtered free from harmful bacteria. We have found that the percolate does, for some months, contain large numbers of potentially harmful bacteria, from which it follows that tipping on the chalk, if fissured, could be dangerous, depending on direction of flow and other factors. Ways of eliminating this particular danger will be discussed later when the experiments

on filtration of water contaminated with refuse constituents have been described (see paragraph 93, *et seq.*). In addition to this, however, we have found that the percolate contains material which cannot be removed by simple filtration and some which may not be removed by any chemical or biological processes which occur naturally underground. If this is so, then refuse tipped say on sandstone exposes the water underneath to risk which, in the case of mineral matter, is just the same as though the tipping had been on chalk, and, in the case of organic matter, is only eliminated if a large amount of purification occurs during the passage of the water through the ground.

56. Now it is thought that in many areas refuse has been tipped on permeable land which was considered to constitute a good filtering medium. It was believed that this would protect the underlying water from contamination. We do not now say that this is not the case. In many instances experience has shown that the ground water has in fact remained potable and we have heard of no case where the quality of a public water supply has been impaired. But this may be because the increase in, say, sulphate and chloride contents has been too small to comment on, or perhaps because mineral analysis is carried out insufficiently frequently. We feel that there must be information in the country on this point waiting to be obtained and we invite the collaboration of local authorities and water undertakings on this matter. For any case in which a refuse tip has been or is about to be formed in such a position that drainage from it could reach a well or borehole used for public supply purposes, we would strongly urge that particulars be sent to the Ministry of Housing and Local Government.

57. Such information would be very useful and might permit of more reliable conclusions being drawn on the matters. Meanwhile we can only say that the tipping of refuse on any permeable land might lead to an increased mineral content of the ground water and that the risk of this happening is not eliminated by a stratum which merely ensures efficient mechanical filtration (but see paragraph 117, *et seq.*).

EXPERIMENTS WITH REFUSE TIPPED INTO WATER

LABORATORY EXPERIMENTS

58. Two laboratory experiments were carried out on the effect of passing water through refuse for long periods. In one of these the water was re-circulated. They are described in Chapter 4 of the detailed Report. They do not bear closely on the problems which immediately concern us (though they were useful as a guide to the larger scale tests), but are included to add to the general fund of knowledge on the subject of refuse disposal. Two points which they brought out, however, are worth mention here.

59. The first is that there was a polluting effluent. The second is that when water was re-circulated through the refuse some elemental sulphur was produced. We have not been able to follow this up, but if it could be shown that sulphate can, in given circumstances, be reduced to sulphur, the fact could be important in preventing sulphate from reaching ground water.

60. It was already well known that the tipping of refuse into water can very seriously contaminate that water and give rise to severe aerial nuisance. The subject has been further studied on the large-scale at Egham, though without such control of the relevant factors as we have been able to exercise at Bushey. By being able to weigh the refuse and tip it in a predetermined manner, and particularly by being able to meter the water passing by or through the refuse, we have been able to acquire some more quantitative information. This we believe to be useful and we devote the present section to it. But we have chiefly regarded the "wet tank experiment" now to be described as a source of suitable effluent for the filtration experiments we shall discuss later, and have made it subservient to their requirements. This is the explanation of the apparently haphazard way in which the tank was filled.

61. The tank, of the same size as the dry tank, was filled in eight unequal stages over a period of 15 months. After complete filling, observations were continued for a further three months. All reasonable efforts were made to keep the face of the refuse as steep as possible, and a floating boom prevented material from floating over the water surface at the front. Expanded metal was used to maintain verticality in the two side faces. Because of these matters it was impossible to consolidate the refuse mechanically. No doubt it was for this reason that the permeability, determined as soon as the pit was completely filled, was high. It is to be noted, however, that it fell substantially during the next two months. This may have been due to natural settlement, to the interstices blocking with trapped suspended matter, or to the growth of anaerobic slimes. It does seem probable, however, that in practice where consolidation can be, and mostly is, practised, the amount of water actually passing through the body of the refuse, apart from rain percolating downwards, would be very small. Very rapid tipping and good consolidation may be one way of greatly reducing the magnitude of ground water contamination.

62. The gradual fall in permeability with time had also been demonstrated in a preliminary experiment in a tank in which water had been re-circulated through refuse for many weeks (see page 87).

63. Common sense suggests that when the large tank at Bushey was only partially filled with refuse the water would preferentially pass round the refuse instead of passing through it. On the other hand when the tank was filled the water had necessarily to pass through the refuse. It is therefore of great interest to note that the composition of the water leaving the tank was not obviously worse in the period following the final filling than at any other time after a quantity of refuse had been tipped. Indeed, determinations related to carbonaceous contaminations were considerably smaller after the final filling, though those relating to nitrogenous contamination showed an increase. Moreover, six months after filling almost all the chloride had been washed out of the refuse, indicating that it had been thoroughly leached. Taken in conjunction with the filtration experiment (paragraph 73) these observations provide good evidence that organic matter from wet refuse slowly undergoes a stabilisation process as a result of which it either becomes insoluble or decomposed. If this is so it provides another reason for rapid tipping and good consolidation so that the organic matter is not washed out for a long time.

64. The bacteriological condition of the water which had been in contact with the refuse is given and discussed on pages 115 to 116. Here it is only necessary to mention those points which appear to be sufficiently clear to be taken as having a general application.

65. First, the bacterial condition of the water became worse after each addition of fresh refuse, and then improved again. The improvement could not have been due entirely to dilution with fresh water, even had no further bacteria been extracted from the refuse after the first day or two. It is presumed, therefore, that the bacteria were dying off, their environment being unfavourable.

66. The second point is that subsequent tipping after the first produced much smaller maximum counts. Taking *coli-aerogenes* as an example, the maximum figure after the first tipping was 24,000,000 per ml. whereas subsequent tippings, except the last, gave maxima never exceeding about 100,000 per ml.; the last maximum was 460,000 per ml. Part of the difference may have been connected with temperature, but it is believed that the main cause was the composition of the water at the time. The first tipping was into clean main water, the subsequent ones were into water heavily polluted and anaerobic. This may well have been antagonistic to bacteria which are important in connection with water supply. Whatever the reason, the smaller effect of tippings after the first one seems an important observation.

CHEMICAL CONDITION OF THE WATER IN THE WET TANK

67. Little needs to be said in general terms about the chemical quality of the water in, and effluent from, the tank, since it was "managed", so to speak, to provide a suitable influent for the filtration experiments. Full details are given in Chapter 6 of the detailed Report. On the whole the effluent had a B.O.D. of the same order as crude sewage. In relation to the B.O.D. the free ammonia content increased with time, presumably due to a progressive breakdown of insoluble protein matter. Chloride was almost completely extracted from the refuse during the period of the experiment. Anaerobic conditions with the presence of some sulphide prevailed throughout (as expected), and may have provided the reason for the small amount of sulphate extracted. This may have been largely converted to insoluble sulphide.

PURIFICATION BY FILTRATION OF WATER CONTAMINATED BY HOUSE REFUSE

68. Laboratory investigation of the long-term oxygen demand of the water in the wet tank, carried out at our request by the Water Pollution Research Laboratory, indicated, within the limits of experimental error, that all the organic matter was amenable to biological oxidation to water, carbon dioxide and nitrate. This was confirmed in larger scale experiments when effluent from the wet tank experiment was passed through aerobic percolating filters of the conventional type. Eventually, therefore, under favourable conditions, the water would become free from organic matter. In practice, unless the amount of pollution were so small that it could be oxidised in the pit itself, most of such purification would have to take place after the water leaves the pit, i.e., below

ground. Here the necessary oxygen could come only by diffusion from the surface (and the rate of diffusion would be expected to be small), and from that dissolved in diluting water (and the amount available from this source would be small too, until the volume of diluting water became very large). There is, however, the possibility of some purification being effected under anaerobic conditions, either by simple filtration or by biological digestion. In practice the water would percolate from the pit into the surrounding land without much initial dilution and the first opportunity for purification would be under anaerobic conditions. It was decided, therefore, to imitate these conditions at Bushey as far as possible, and at the same time to carry out a few tests on purification under fully aerobic conditions.

69. A description of the set of horizontal (anaerobic) filters used is given on page 98. Inevitably they had to be specially filled, and the condition of the medium could not therefore be precisely the same as in nature. The percentage of void space, for instance, was likely to be greater. However, if there were no void space underground, there would be no water flow, so that the difference between natural and experimental conditions could only have been of degree and not of kind.

70. It is considered that the efficiency of purification is more likely to depend on the size of the voids in a medium rather than on the size of particle constituting the medium, although of course if the latter were large and the voids small, a large amount would be required to give the same volume of voids. Now the superiority of sand as a purifying medium is evident from the experiments described in Chapter 5 of the detailed Report. In many cases the natural voids in strata adjacent to sand or gravel pits are more nearly the size of those in sand than those in the gravel used in the coarse filter, which was graded. Thus we believe that the results given with the sand filters are the most important. In nature, however, lengths of strata of mixed sand and gravel required to produce the same number of voids as say 24 ft. of graded sand will be more than 24 ft. But it can hardly be very many times it, or else the rate of travel of water would be so very slow that the strata would be considered almost impermeable. It seems, therefore, that, if the surroundings of a wet pit can be assumed to be gravel or sand, then at a distance of not many times 24 ft. from the edge of a pit filled with refuse, the water is unlikely to remain more polluted than it was after the 24-ft. sand filtration experiment. This has not yet been proved, but it seems a reasonable basis on which to plan a full-scale trial which can be kept under close observation.

BACTERIOLOGICAL PURIFICATION

71. It can be seen from Table XXIX, page 134, that the effect of filtering through 24 ft. of sand was to reduce the count of *coli-aerogenes* organisms by at least four orders of magnitude. The same figure applies to *E. coli* (Table XXXI) and presumably (though the figures would be the same for any order of magnitude above three) to faecal streptococci (Table XXXIII, page 136). Even 6 ft. of sand reduced the numbers by two orders of magnitude. Thus, provided the equivalent of 24 ft. of sand must be traversed by water from a wet pit containing refuse before reaching a source of water supply, it is unlikely that there will be significant bacterial contamination. The story is different, however, with other sorts of contamination.

72. Neglecting (for the moment) ammonia and inorganic matter, it is plain from Table XIX, page 120, that some purification occurred in all the filters, particularly the sand filters, and that the degree of purification increased with the length of filter. The percentage reduction by sand in permanganate value, B.O.D., organic carbon and organic nitrogen averaged over the whole period was as follows:

Percentage Reduction

	Permanganate Value	B.O.D.	Organic Carbon	Organic Nitrogen
6 feet ..	65	55	55	60
12 feet ..	60	50	45	55
18 feet ..	70	75	55	60
24 feet ..	80	85	65	60

73. It is considered significant that the rate of removal of each of the above constituents was not far from being the same. Moreover, the relative inefficiency of the 12-ft. filter, for which the reason is unknown, was equally obvious with each constituent. It seems from this that the purification being effected was a general purification, and not a selective one. For this reason, and also because there was no evidence of the degree of purification falling off asymtotically with length towards any figure less than 100 per cent, it can be concluded that it would have proceeded a good deal nearer to completion had the filter been longer than 24 ft.

74. Now it is hardly conceivable that water pumped from underground would ever be composed entirely of that which has passed through refuse. Even if the point of pumping lay in the direct line of travel of water from a filled pit, a cone of depression would be established which would drain water from other directions too. Usually the water from a pit will become progressively diluted with the kind of water normal to the area, which will contain some oxygen dissolved in it (and perhaps oxygen in the form of nitrate too). When this occurs, purification by oxidation will begin. If, at this stage, the water polluted by refuse had already undergone 90 per cent or more purification by anaerobic reaction, then the amount of further purification required would be proportionately smaller and so would the oxygen required for the purpose; and the amount of diluting water too. Thus the fact we have established that general purification from organic matter can be effected under anaerobic conditions is likely to be of great practical importance. It is only necessary to look to diluting water and other sources of oxygen to provide a very small proportion of the total oxygen requirements. In making estimates, however, it is necessary to bear in mind that uniform dilution will not take place and that it would be a grave disadvantage if ground water at a source of abstraction became completely de-oxygenated. The water might acquire an offensive smell and be subject to the growth of filamentous organisms, particularly if traces of iron are present.

REMOVAL OF AMMONIA

75. The water from the refuse had a content of ammonia which, in general, increased with time. This is attributed to a decomposition of protein matter the speed of which increased as suitable bacteria developed. The concentration

reached its peak when the pit was completely filled. At that time the reaction was presumably well established in the refuse which had previously been tipped and the completion of filling forced more water through that refuse. Afterwards the concentration of ammonia began to fall but observations had to cease before it fell to figures characteristic of the first few months. As a consequence, the horizontal filters were, in general, fed with a liquid containing gradually increasing amounts of ammonia. In these circumstances it is impossible to deduce from the results the exact mechanism by which it was removed. We are certain that experiments under more controlled conditions, as well as experience on the large scale, are needed on this point.

76. That some removal of ammonia took place during filtration is plain. It is equally plain that the proportion removed was much smaller than that of the organic constituents. Removal in the coarse filters was not detectable; in the medium filter it was still quite small; but in the longest sand filter it averaged 40 per cent over the period of the experiment. The monthly figures, however, varied over an enormous range. In the first three months, and while the free ammonia entering the system was small, the proportion removed exceeded 95 per cent. In the eighth month, however, when the ammonia entering had dropped to 3·6 p.p.m., after having reached 34·6 p.p.m. in the fifth month, the ammonia leaving was three times as great as that entering. Careful examination of the results, however, reveals a distinct pattern, and this, together with further experiments carried out, permits the following explanation being offered.

77. Either the sand or the organic material deposited within it, or probably both, has base-exchange properties by means of which ammonia can be removed from solution and held back on the solid. A proportion of the ammonia is held back strongly, while part is only weakly held and can be removed with water not containing ammonia. That much is only very weakly held was shown by passing tap water through some of the filters after the test with refuse-contaminated water had been concluded. In all cases the filtrate contained some ammonia, there being more in those filters which had previously removed more ammonia, and in the case of the 24-ft. sand filter, the concentration was as great or greater than it had been during the previous month when it had been treating an ammonia-containing liquid. That some of the ammonia was strongly held was shown by shaking a sample of the used sand with successive quantities of water until little more ammonia was removed, then shaking with a salt solution. Further quantities of ammonia were then extracted.

78. It seems, therefore, that if water passes through refuse (and this presumably applies to both dry and wet tipping) and then through a very long length of sand the following processes will occur. Contaminated water which first passes through the sand will have its ammonia progressively removed until it is substantially ammonia free. The sand first receiving the water will absorb less ammonia subsequently, so that as time passes it will take longer and longer lengths of sand to remove the ammonia. Eventually the water leaving the refuse will become less contaminated and finally will contain no ammonia at all. As soon as the concentration of ammonia in the water entering the sand falls, it will pick up some of the loosely held ammonia there and the total result will be that the loosely held ammonia in the sand will travel slowly along, much more slowly than the water. Not all the ammonia will travel like this, however, because that which is firmly held on the sand will remain where it was absorbed and eventually, when oxygen becomes available, be oxidised to nitrate. Thus

the slowly moving region of ammonia will become less and less concentrated until movement stops altogether after which oxidation will slowly take place. Beyond this point there would clearly be no risk of ammonia in the ground water. Also the belt of ammonia will act as a buffer to balance out variations in the ammonia content of the water passing through it. Diffusion and dilution will greatly influence these processes. The diffusion of contaminated water outwards will bring more and more sand into operation as a base-exchange agent and thus speed up the ammonia removal. Diffusion of uncontaminated water into the contaminated water will dilute the ammonia without removing that which is firmly held on the sand and provide oxygen for its oxidation. Eventually all the ammonia will be converted to nitrate which will dissolve in the water. A rough estimation, such as we have suggested should be made for chloride, should be sufficient to check that the nitrate content of a source of water which might be affected is not likely to become undesirably high.

79. The interpretation of all this in relation to practice is not easy. Clearly the base-exchange capacity of the medium through which the water will flow is an important, and probably the dominating factor. Some sands in this country have a high base-exchange capacity and in such strata the risk of ammonia produced from refuse travelling far is probably zero. This might also be true if the stratum through which the water percolates contains even small amounts of clay, which has usually a considerable base-exchange capacity. Other materials have a base-exchange capacity which for ordinary purposes would be considered negligibly small, but for the present purpose a large one is not required. The total amount of ammonia from refuse proved to be of the order of 1-lb. per ton, and in a particular case it might be readily apparent that the water containing it would have to pass through, say, 100 tons of sand for every ton of refuse deposited. A base-exchange capacity of 1-lb. per 100 tons would therefore suffice.

80. It is considered therefore that useful guidance would be given by laboratory determinations of base-exchange capacity with respect to ammonia of samples of the material through which the ground water flows.

OTHER MATTERS ARISING DIRECTLY OR INDIRECTLY OUT OF THE EXPERIMENTS

81. The matters dealt with in this section could not properly be placed in either of the two preceding sections. Some require reference to the results of both the dry and wet tipping experiments. Others are more speculative, but the experiments nevertheless have a bearing on them.

ASSESSMENT OF RELATIVE DANGERS TO GROUND WATER OF DRY AND WET TIPPING

82. We have not been able to make our conclusions on the dangers of wet tipping as definite as could be wished. There is, however, a body of practical experience with dry tipping on the large scale on permeable ground. That experience has not yet been collected and studied, and we do not know to what conclusions it will lead. We have said, however, that we have not heard of a case of the quality of a public water supply being impaired. In these

circumstances it would obviously be helpful if the magnitude of the danger from wet tipping could be compared with that from dry tipping, and some of the data obtained at Bushey helps this assessment to be made.

83. The first point is obvious. Refuse tipped wet imparts some pollution to the water immediately, whereas when tipped dry there is a delay of three or four months before water leaves the refuse and a further interval of unknown duration while the percolate passes through the ground to the water table. This obviously gives a much better opportunity for a measure of purification within the refuse itself and for potentially dangerous organisms to die off. The fact that dry tipping results in the production of high temperatures throughout a large proportion of the refuse may also be an important factor operating in the same direction.

84. Secondly, while percolate from the dry tip is passing down to the water table, its environment may be accessible to at least a limited amount of air, so tbat some aerobic purification will take place. Such purification before reaching the water table cannot take place with a wet tip.

85. As against this, however, it will usually be the case that the water table in wet tips will be much nearer the surface of the ground than in the case of dry tips, and will receive air by diffusion more rapidly, thus permitting an increased rate of aerobic purification.

86. The above points cannot be assessed quantitatively. One can, however, compare figures for the total amount of organic polluting matter extracted from the refuse in the two conditions. The figures given in the following table are in kilograms per 100 tons:

Kilograms per 100 tons Refuse leaving Dry Tip by way of Percolation and leaving Wet Tip in the water passed through

Tip	Period	B.O.D.	Permanganate Value 4 hours	Organic Carbon	Organic+ Ammoniacal Nitrogen
Dry Tip ..	2 years, 4 months	226	34	148	40·0
Wet Tip ..	1 year, 6 months	468	54	258	44·0
Ratio $\frac{\text{Wet Tip}}{\text{Dry Tip}}$		2·1	1·6	1·7	1·1

87. It should be noted that at the end of the period of measurement the refuse tipped wet was giving a worse percolate than that tipped dry, and the figures will be in error on that account. Nevertheless the trend of the monthly analyses (see Table XIII, page 114) taken after the tank had been completely filled was so sharply downwards as to suggest that not a great deal of readily extractable matter remained in the refuse. Analyses of the refuse itself at the end of the test confirmed this. The error is therefore not likely to be large.

88. The agreement between the ratios between the wet and dry tips is by no means absolute, but appears sufficiently close to justify the general conclusion that organic matter extracted per ton of refuse tipped wet is probably about twice that from refuse tipped dry. This seems to us to be an important finding and in certain circumstances it might form the basis of a rough and ready assessment of the danger to ground water of tipping house refuse into water.

89. Our filtration experiments have been conducted with the sort of liquid produced when refuse is tipped into water. We have carried out no experiments on anaerobic filtration of the percolate from a dry tip. The two liquids are of the same general nature but vastly different in concentration; the dry tip percolate is many times stronger. At the same time, other factors being equal, there is a great deal less of it, and the total polluting matter per ton, is as we have already explained, greater in the case of a wet tip.

90. Water contaminated by refuse tipped wet is already in the water table and will travel through the ground in a more or less horizontal direction, becoming diluted only gradually. Percolate from a dry tip will first travel vertically downwards into the ground until the water table is reached. At that point it will be substantially diluted and thereafter travel with the water in the water table. After this stage further purification will occur and it seems that the smaller of our filtration experiments on percolate from the wet pit will be equally applicable to dry tipping.

91. There is, however, the additional point that before reaching the water table a dry tip percolate will trickle downwards through a medium containing, initially, air. It may be thought that the air will effect a great amount of purification. This we believe to be doubtful; certainly it cannot be relied on. It seems to us that the rate of oxygen demand of the percolate must be very many times greater than the rate of oxygen supply through diffusion, and that the medium must soon become, and thereafter remain, anaerobic. Such purification as takes place as the liquid descends must be of the same general type as that occurring in our filters and the results of our experiments should therefore apply in a qualitative way.

92. In all, under comparable conditions, dry tipping is less likely than wet tipping to affect a water supply adversely, because (*a*) the quantity of polluting matter extracted is smaller, (*b*) the polluting matter is extracted only after a considerable delay which allows decomposition to take place and (*c*) the polluting matter has an additional opportunity for filtration and purification as it descends to the water table.

DISCUSSION OF WAYS IN WHICH USE COULD BE MADE OF SITES LYING ON POSSIBLE FISSURED FORMATIONS FOR THE DRY TIPPING OF HOUSE REFUSE WITHOUT RISK TO GROUND WATER QUALITY

93. We believe that our experiments have indicated that ways may exist by which fissured land may be so used for the dry tipping of refuse as to eliminate or greatly reduce the risk of contaminating ground water. A brief account of them follows. Not all the ways would apply to every case, nor are the merits of them as fully supported as we would desire. Each should be critically considered in the light of local circumstances, and they may then be helpful.

94. *Importance of selection of sites*.—It is obvious that, for many reasons, some sites are more dangerous to ground water than others. A wise choice can reduce the danger. There is no need to elaborate on this.

95. *Re-use of "safe" sites.*—It has been established that the ability of refuse to contaminate water rapidly diminishes with time after tipping. In our experiment after two years the potentially harmful bacteria in the percolate were almost negligible, the organic matter was greatly reduced and the chloride had almost gone, though sulphate was still present. This opens up the possibility of excavating refuse which has been tipped for two years or more on a "safe" site, tipping it on a site which would have been dangerous for fresh refuse, and using the original "safe" site again, perhaps repeatedly. Even then it would be prudent to avoid making the final tip on fissured formations within a short distance of a point of water abstraction.

96. *Treatment of the base of the tip.*—It is obvious that if the base of the tip is waterproofed, e.g., with puddled clay, no percolate can enter the ground. It would be essential, of course, to provide another outlet for the percolate and it might well be necessary to collect and purify it before disposing of it. Our experiments have shown that the percolate can be purified biologically.

97. *Treatment of the surface of the tipped refuse.*—If no water reaches the refuse there can be no percolate from it. One way of achieving these conditions would be to cover the refuse with an impervious material, e.g., clay, and arrange for easy run-off of water reaching the clay. This, too, is obvious, but our experiments supply an answer to at least one question that might be asked concerning it. They have demonstrated that house refuse has a capacity for absorbing and retaining a good deal of rainfall; hence no percolate is produced for several months depending on the depth of tipping. It appears to follow that provided tipping is carried out sufficiently rapidly to ensure that no percolate arises from one layer until the next is tipped, and provided the waterproof cover is laid shortly after the final layer is tipped, then the methods will be effective. The fact that a waterproof cover is absent while the tip is being constructed is of no moment.

98. *Tipping under conditions where the percolate is exposed to aerobic action.*—This is a much more speculative idea, necessarily so because we have no full-scale experiment to confirm the possibilities which it opens up. Further, refuse is not at present so tipped that the percolate is exposed to conditions favouring biological oxidation before it enters the ground. But it could be, at a cost, if it were found desirable. We believe that the indications are that its adoption would often enable refuse to be disposed of safely where normal tipping would be dangerous. To establish this, so far as it is possible at present, it will be necessary to refer in some detail to several pipe experiments which are recorded in different parts of the Report of the investigation.

99. It has been pointed out that in the dry tank test the percolate contained no oxidised nitrogen. Naturally so; there was no possibility of oxidation occurring, for air could have had no means of access to the bottom of the tip. Now in the initial pipe experiments no deliberate provision was made for aerating the refuse, but the set-up was such that air could reach the underside of the refuse. The refuse was placed on 3-ins. of gravel which was itself held on a perforated metal plate exposed to the air. We can see no possible reason other than this why the percolates should have contained large concentrations of oxidised nitrogen.

100. That they did so is shown on reference to Table III, page 55. The first two experiments can be neglected, since they were highly artificial and the

conditions did not approach what would normally occur. Even here, however, a very large measure of ammonia oxidation was ultimately established. In the third experiment, which was under conditions of natural rainfall, the very first percolate was highly nitrified. In all, and taking into account the volumes of percolate, the total amount of nitrate nitrogen was at least 10 times the amount of ammoniacal nitrogen and, after seven further months, the total contents of both ammoniacal and nitrate nitrogen were almost negligible. At the same time the B.O.D's. of the percolate were less than 5 per cent of those of the percolate obtained at Bushey. The bacteriological condition of the percolate was also improved by two or three orders of magnitude. It must be admitted that the improvement in organic nitrogen and organic carbon was only about two- or three-fold and there was little reduction in permanganate value. All in all, however, access of air to the base of the refuse brought about a very large improvement in the condition of the percolate.

101. Two further pipe experiments on similar lines were later carried out at Bushey (see Tables XXII and XXIII, pages 83 to 84). One of them (A) was virtually a repetition of the one just discussed, but it was set up primarily to provide a comparison to pipe (B). It gave very similar results. Again they were characterised by B.O.D's. only a very small fraction of those in the tank percolate at comparable times and a substantial degree of nitrification initially, increasing to almost complete nitrification after a year.

102. The second pipe experiment (B) was identical with the first except that the 3-ft. depth of refuse rested on a 3-ft. layer of medium ballast. This also was open to air and formed an aerated biological filter. The differences between this and pipe (A) and the tank experiment were striking. The initial percolate had a B.O.D. of only 100 p.p.m., compared with 300 p.p.m. in pipe (A) and about 7,000 p.p.m. in the tank experiment. Eighteen days later it was only 5 p.p.m., whereas in the tank experiment no reduction was shown in that time and in the case of pipe (A) the figure of 5 p.p.m. was only reached after 100 days. The free ammonia content of the effluent from pipe (B) was always low (2 to 3 p.p.m. compared with 500 to 700 p.p.m. in the tank experiment) and nitrification was virtually complete. That very large reductions also occurred in the organic carbon content and the organic nitrogen content (though not quite so large as in the case of B.O.D.) is apparent when Tables XXII and VIII, pages 83 and 64, are compared. In relation to the percolate from the tank test it is not too much to say that the 3-ft. ballast filter under refuse in the pipe experiment plus material aeration had effected a 99 per cent improvement.

103. The bacteriological examination of the effluent from the ballast filter gave even more striking results (Table XXIII, page 84). The first day's percolate gave a figure of 750 *E. coli* per ml. (compare 390,000 for the tank experiment and 15,000 for pipe (A)); on the following day the figure had been reduced to 4 per ml. and five days later no coliforms of any type and no faecal streptococci were found, nor were they found subsequently. In the effluent from pipe (A) these organisms persisted in relatively small numbers for 250 days. It is not perhaps so surprising as at first sight it seems that a 3-ft. depth of ballast should effect such an amount of purification. Assuming a percolation of 8-ins. per year, the dose to the filter corresponds to only 0·1 gallon per cub. yd. per day, compared with the normal load on a sewage filter of 70 gallons per cub. yd. per day. Taking the B.O.D. of the unoxidised percolate as 6,000 p.p.m. initially, the B.O.D. loading works out at only 0·006-lbs. per cub. yd. per day,

compared with a loading for sewage of at least 0·1-lbs. per cub. yd. per day. Later, of course, the loading would be much less.

104. The effluent from the ballast filter was not, of course, fit to drink. But it was bacteriologically almost sterile and organically almost completely purified and, if the dilution underground had been adequate to deal with the mineral constituents, it would not have affected the potability of ground water even had it flowed straight into fissured chalk.

105. The practicability of operating such a system of tipping no doubt depends on circumstances. It can be calculated that the amount of air needed would be very small indeed and it should cost very little. If the ultimate depth of tip is to be large the provision of a 2-ft. or 3-ft. layer of aerating medium (clinker, gravel, crushed stone, or crushed chalk), sufficiently robust to support the weight of the refuse without collapsing, might not be unduly expensive.

106. It is to be emphasized that we have no evidence from large-scale trials that this method of tipping would be sufficient to protect ground water. We do think, however, that it promises well and that it is worth while trying it out as an experiment on the practical scale.

DISCUSSION OF WAYS IN WHICH USE COULD BE MADE OF WATERLOGGED SITES FOR THE DISPOSAL OF HOUSE REFUSE WITHOUT RISK TO GROUND WATER QUALITY

107. In the first place we must reiterate what we said earlier that our experiments have not been concerned with atmospheric pollution and we are not considering it in this section. It must not be assumed that the suggestions we now make for avoiding risk to ground water quality will all reduce the risk of aerial nuisance, though some of them no doubt would.

108. It must be further emphasized that we are only making suggestions, not recommendations. It is clear that further investigations are required and in some cases our suggestions must be taken as being no more than our ideas on matters which would probably repay investigation.

Selection of suitable sites

109. Our analyses and filtration experiments have indicated that where ground surrounding a site is a suitable filtering medium, if there is sufficient of it between the site and a source of water abstraction, and if dilution water is adequate, then the site could be used for house refuse disposal without risk to that water. Given sufficient geological and other information, we think our figures could be used to calculate, in an approximate way, the risk attached to the use of any particular site.

Tipping of old refuse

110. Our experiment with refuse tipped dry to a depth of 5 ft. showed that after two years the amount of extractable pollution was very small. Presumably such refuse could be tipped into water with very little if any danger to water supplies, leaving the original site to be used again. The cost of double tipping would be the price paid for safety, but in some cases it might be well worth while.

Preventing or delaying extraction of organic matter

111. Mention has already been made of the evidence for the slow stabilisation or decomposition of organic matter in refuse over a period of time. It appears to follow that if refuse is so tipped into water that leaching is largely delayed, then the total pollution eventually washed out will be considerably reduced. This can obviously be best achieved by more effective consolidation than was possible in our experiments.

112. It seems likely that the degree of consolidation which can be achieved in wet pits is not so great as on dry sites, but the aim should be to achieve the best possible in the circumstances.

113. There does not appear to be any practicable way of preventing pollution being leached from the advancing face of the tipped refuse. It should be possible, however, so to tip that the exposed face is always kept at a minimum. It might also be feasible to cover with inert material any face which is not to be tipped over for an extended period.

114. It might also help to reduce the organic matter extracted quickly if the surrounding water could be contained rather than allowed to diffuse over the whole body of water in the pit. This could be done by tipping banks of inert material so that small lakes were formed, and then filling them one at a time with refuse.

Methods of increasing the rate of purification of polluted water

115. Any aeration of the polluted water will in some measure affect purification, but whether it would be practical to accomplish sufficient to make it worth while is not known. (This is not a comment on aeration for the purpose of odour control.)

116. It might also be possible to provide additional filtration, if the direction of movement of the ground water were known, by tipping from the downstream end upwards. Then water leaving newly-tipped refuse would first either have to pass through older refuse or take a longer way round. In the latter case there would be more opportunity for purification. In the former the extract would be passing through an environment already acclimatised to the anaerobic decomposition of organic matter and purification might be accelerated. This, however, is little more than speculation.

SULPHATE

117. We are returning to the subject of sulphate again to emphasise that we have not been able to solve the problem which it poses.

118. In connection with the dry tank experiment we have already pointed to the great variability in sulphate content of the percolate and the fact that much of the sulphate in the refuse was fixed as insoluble sulphide in the tip. Nevertheless we were able to calculate the total sulphate leaving as such during the course of the experiment and, assuming it to pass unchanged through the ground, its effect upon water later abstracted. The results of the wet tank experiment and the filtration tests were most confusing but nevertheless suggested that the above assumption was unduly pessimistic.

119. The concentration of sulphate in the water leaving the wet tank was smaller than in the percolate from the dry tank. This is understandable: the dilution was so much greater. The concentration always increased after a new batch of refuse had been tipped in the winter, presumably due to simple solution, but not after refuse had been tipped in the summer, presumably due to increased activity of sulphate reducing organisms. The rate of reduction of sulphate after each tipping was also greater than the rate of reduction of chloride, which is also extracted by simple solution, and this again suggests that sulphate reducing bacteria were active. It is also to be noted that on many occasions the sulphate content of the liquid leaving the refuse was much smaller than that of the water passed through it. In all, 150 kg. of SO_4 were contained in the inflow water whereas the effluent only contained 125 kg. SO_4. The net effect of the refuse was actually to remove some sulphate from the water, not to add to it. There is thus ample evidence that, in some circumstances, sulphate from refuse will not contaminate ground water, at least so long as anaerobic conditions exist in the near vicinity.

120. Insofar as sulphate was concerned the filtration experiments gave many anomalous results. Generally the coarse ballast did not remove much sulphate, which is understandable, though, oddly enough, the short ones had a greater effect than the longer ones. The medium ballast did remove sulphate, up to 50 per cent or more, its efficiency increasing with length. The 6-ft. sand filter also effected some removal, about 50 per cent. But the longer sand filters, though effecting some removal during the first few months, later produced effluents containing more sulphate than did the influent. This was particularly the case with the longest filter of all. This cannot now be explained; it may have been that the sand itself contained sulphate, but it is not clear why this should not have been washed out in the earlier stages of operation.

121. It does, however, seem safe to say that the passage of water contaminated with refuse through a permeable sub-soil at least delays the passage of sulphate, so that it will reach a given point during a longer interval than, say, chloride and therefore at a reduced concentration. Such a delay took place in each of the 12 filters. Taken in conjunction with the evidence of sulphate reduction in the water in the wet tip, and also in the dry tip, it seems fairly certain that the assumption that all the sulphate in tipped house refuse will find its way within a few years into ground water errs greatly on the side of safety. It is impossible to estimate the magnitude of the error and further information is clearly needed. Some useful indication may well be forthcoming in response to what we have said in paragraph 56.

IRON

122. Only two determinations of iron were made in the percolate from the dry tip. One gave figures 3·5 p.p.m. soluble iron and 2 p.p.m. insoluble iron and a later one 1·5 p.p.m. total iron. In comparison with other constituents it can be neglected entirely and no further analyses were carried out on the percolate. At the end of the experiment, the amount of extractable iron in the remaining refuse was small compared with B.O.D., sulphate and some other items, and we concluded that, provided these gave no trouble, iron would not.

123. Because of this, and because it was impracticable to analyse every sample for every constituent, determinations of iron in the wet tank experiment were made only infrequently. One was made of water which had passed through the tank one year after filling had commenced and one month after the last addition of refuse. At that time the B.O.D. was very high and the total iron content of only 6 p.p.m. suggested that iron as a contaminant need not be further considered. However, a further determination near the end of the experiment, gave 50 p.p.m. total iron of which 40 p.p.m. were in solution. At that time B.O.D's. were only about 50 to 100 p.p.m. and rapidly falling with time, so that the iron content was very significant indeed. However, the iron contents of the effluents from the filter indicated that iron was being removed about as quickly as organic matter. We still think it likely that iron will not contaminate ground water unless other objectionable constituents do, but we would be happier about the position if we had more information. This is one of the matters on which further work is required, because iron in ground water can be a source of much difficulty.

THE EFFECT OF CONSOLIDATION

124. The refuse tipped wet at Bushey could not be consolidated in any effective way. None the less three months after the tank had been completely filled, the permeability of the refuse was little greater than that of a medium sand, and about the same as that of the refuse tipped dry which had been much better consolidated initially. Its bulk density of 9-cwts. per cubic yard was not far from that generally found in practice for a well-consolidated dry tip. This is not perhaps surprising for the movement of small particles relative to each other will be easier in water than in air. In practice, tipping into water is usually continued to well above the water level and the refuse below is consolidated, though not so effectively as a dry tip, by bulldozers and other heavy vehicles operating on the surface of the refuse. Moreover, conditions may well be such that watery slimes will develop in the interstices. It is thus likely in practice that the permeability of the refuse below water will be a good deal less than was the case at Bushey. Unless the refuse is tipped within the cone of depression of a point of abstraction of ground water, the hydrostatic head across the refuse will be small. Consequently the rate at which water passes through the refuse may be very small and the rate of abstraction of organic matter, after the rapid abstraction during the tipping process, may also be much slower than at Bushey. Good consolidation is obviously advantageous.

125. It must not be forgotten, however, that the refuse above the water-line will be subject to rainfall and consequent percolation. The percolate must either pass through the water-logged refuse or, if this becomes completely impermeable, along the base of the overlying refuse tipped dry.

27th June, 1960.

Detailed Report of the Investigation by the Department of Scientific and Industrial Research, Laboratory of the Government Chemist.

CONTENTS

Report on Refuse Disposal Experiment

SUMMARY

Chapter 1.—This reviews the literature concerned with polluted water arising from the tipping of garbage and refuse and the effects of the pollution. It also includes a section on percolation, evaporation and run-off.

Chapter 2.—This gives an account of preliminary experiments carried out at the Laboratory of the Government Chemist on the dry tipping of refuse. The refuse was exposed to different rates of rainfall, and the effect of this on the chemical and bacteriological character of the percolates is described and discussed.

Chapter 3.—A full description is given of an experiment at Bushey in which 90 tons of house refuse were tipped into a tank from which the percolate was measured and sampled. Records of rainfall and percolation over 2½ years are given, the chemical and bacterial composition of the percolates are recorded, and the total amount of polluting matter leached from the refuse is computed. This is compared with the analysis of the refuse when tipped and at the end of the experiment. The results are fully discussed.

Chapter 4.—Preliminary experiments at the Laboratory of the Government Chemist on the tipping of house refuse into water are described. They include one in which water was passed through the refuse once only and one in which water was re-circulated. An experiment in which the liquor was filtered through chalk under aerated conditions is also included.

Chapter 5.—This describes the design and method of operation of the wet tipping experiments with 110 tons of house refuse at Bushey and the subsequent filtration experiments. The refuse was tipped in a controlled manner and the rate of flow of water through the refuse tank and each of 12 horizontal filters was also strictly controlled. The permeability of the tipped refuse is also discussed.

Chapter 6.—Here all the results of the experiment on wet tipping at Bushey are given. They include the times and quantities of tipping, the rates of water supply and the chemical and bacteriological analyses of the water after passing the refuse and after filtration. All are discussed.

1. Review of the Literature

Disposal of Refuse in Tips

When comparing observations made in different countries on the pollution of underground water caused by refuse disposal, due regard must be given to the character of the refuse. In the United Kingdom house refuse differs from that collected in some other countries in its high content of ash derived from the burning of coal and coke in open fireplaces and in domestic boilers. The proportion by weight of ashes and cinders varies from over one-half in winter to slightly under one-third in summer. Analyses of United Kingdom house refuse are given on pages 43 and 109.

Calvert (1), U.S.A., reported an increase in hardness, calcium, manganese, total solids and carbon dioxide in wells 500 ft. from an impounding pit from a garbage reduction plant. Lang (2), Germany, describes how the leachings from a garbage dump reached wells 1,476 ft. away causing an increase in total solids from 360 to 552 p.p.m. and in hardness expressed as $CaCO_3$ from 190 to 272 p.p.m. He also quotes (3) a case where garbage dumped in a sand-pit caused inorganic pollution in wells 2,000 ft. away for 15 years after dumping had ceased. Carpenter and Setter (4), U.S.A., sampled the water at the bottom of a refuse pit or sanitary landfill by drilling experimental bores and quote the following results:

Units p.p.m.	B.O.D.	Alkalinity, as $CaCO_3$	Chloride, as Cl
Maximum ..	7,330	9,450	12,300
Average ..	1,987	2,867	2,406

Eliassen (5) stated that rapid stabilisation of refuse occurred when the moisture content lay between 40 and 50 per cent. The waste paper in garbage was relatively dry with a moisture content of 10 per cent, and tended to absorb moisture from the organic matter thus delaying decomposition and stabilisation. Reduction in paper content of the refuse was shown experimentally to result in an increased rate of decomposition.

At Krefeld, Germany, Roessler (6) studied the effect of garbage dumped in a wet gravel pit on private and municipal wells situated from ½ to 4 miles distant from the pit. Wells in the down-stream direction of the underground water flow showed an increase in total hardness, sulphate and chloride compared with wells up-stream from the pit and this persisted from 8 to 18 years. Iron, manganese and ammonia were present in traces only and although bacterial counts were high, the coliform test was negative. The State Water Pollution Board of California (7) has reported an investigation on the leaching by rainfall of incinerator ash dumps. They concluded that the maximum amount likely to be removed from 1 cub. yd. of incinerator ash in a five-year period would be 5·3-lbs. chloride (Cl), 5·0-lb. sulphate (SO_4), and 2·92-lb. sodium. During the reclamation with house refuse of a disused wet clay-pit at New Malden in 1952, Apse, Morwood and Wood (8) observed that nuisance due to

the evolution of hydrogen sulphide completely ceased after contractor's rubble containing chromate waste had been tipped into the pit. The water in the pit then contained 480 p.p.m. chromate as CrO_3 and was sterile. The addition of chromate waste was adopted as a means of keeping aerial pollution under control. The chromate concentration was found to fall gradually due to a reduction and when it approached zero, sulphate-reducing bacteria again became active. Weekly additions of 750-galls. of chromate waste containing 7 per cent CrO_3 were sufficient to prevent nuisance when tipping domestic refuse at the rate of 175 tons per week. Drummond and Postgate (9) investigated the population of sulphate-reducing bacteria in this pit and concluded that chromate at concentrations lower than 20 p.p.m. CrO_3 had a specific effect in preventing the multiplication of these bacteria even though other bacteria associated with polluted water were able to grow. At these low concentrations they considered that the effect of chromate was bacteriostatic rather than bacteriocidal.

The effect of reducing the area of exposed water in a wet pit into which house refuse screenings were tipped was investigated in 1950 at Sunbury by Knolles (10). Clinker, which was stated not to be polluting, was used to enclose a small tipping area from the clear water of the pit. As tipping proceeded some evolution of hydrogen sulphide occurred, but this was not sufficient to be regarded as a nuisance. Seeding the lagoon into which refuse was tipped with cultures of *chromatia*, in the hope that they would utilise the hydrogen sulphide, was investigated but proved to be without effect. From the experiment Knolles concluded that aerial nuisance would most likely be avoided if tipping occurred at a rapid rate in cold weather into a small lagoon separated from the main body of water in the pit by an impermeable barrier of destructor clinker. Furness (11), U.K., described methods employed at Egham from 1951 to 1954 to reduce aerial pollution by hydrogen sulphide during the tipping of unsorted house refuse at the rate of 500 to 750 tons per week into a 6-acre gravel pit with an average water depth of 12 ft. The method adopted to prevent the spread of refuse over the water surface was to enclose small areas completely from the main body of water by tipping fingers of refuse across the pit and then to tip into the enclosed area until it was filled. After two months backfilling, the water contained no dissolved oxygen, the B.O.D. was 30 p.p.m., and the sulphate content 250 p.p.m. as S. With the onset of anaerobic conditions sulphate-reducing organisms became active and nuisance from hydrogen sulphide occurred.

Cultures of two sulphur oxidising bacteria, *chlorobium* and *chromatium* were seeded into the water of the pit, but their addition failed to mitigate the nuisance. Chemical oxidation of the hydrogen sulphide by the application of bleaching powder was attempted but abandoned because of its relative ineffectiveness and of the difficulty in handling and spreading the powder. The nuisance was largely overcome by blowing air into the water of the enclosed area through submerged perforated pipes at the rate of 250 cub. ft. per minute. Aerobic conditions, however, were never attained because the pollution load with continuous tipping was too great. The B.O.D. of the water was, however, reduced from 1,300 to 900 p.p.m. and the sulphide content kept at a low value. During the experiment the spread of pollution in the ground water was investigated by the examination of samples drawn from the water in nearby unfilled wet pits and neighbouring wells. Plate counts were low and coliform

organisms were absent in a 12-ft. well 75 yds. downstream from the experimental pit. Some organic pollution was indicated by the B.O.D. which increased to a maximum value of 10 p.p.m. Ammoniacal nitrogen was very high and reached a maximum value of 25 p.p.m. Total solids, hardness, alkalinity and chloride were several times greater than in the unpolluted ground water. The only effect detectable in a well half a mile down-stream in the direction of the underground water flow was an increase of 60 p.p.m. in the chloride content. The author considered that aeration was satisfactory for combatting nuisance if combined with intermittent tipping of dry house refuse particularly if it had stood for one year or more.

In a later paper Furness (12) described work begun in 1955 at Egham where house refuse was tipped into a gravel pit of 40 acres with an average water depth of 12 ft. To prevent the main body of water becoming septic, causeways of clay and rubble were constructed across the pit thus isolating a small area into which refuse was tipped. The first small enclosure of half an acre was rapidly filled in 19 days during April without aeration. The water in the pit, initially saturated with oxygen rapidly became anaerobic with a B.O.D. of 410 p.p.m., and a sulphate content (as SO_4) of 300 p.p.m. No sulphide, however, developed and no nuisance occurred. In subsequent tippings the enclosed area was larger and aeration at rates up to 850 cub. ft. per minute was applied in an attempt to maintain dissolved oxygen in the water. This was not achieved during the filling of a 3-acre enclosure during summer when tipping was at the rate of 1,500 tons a week. The water remained anaerobic, sulphide concentration increased to 29 p.p.m. as H_2S and some aerial nuisance occurred. In the third enclosure of 2 acres, aeration was successful in maintaining aerobic conditions during winter tipping at the rate of 7,000 tons a month, and although the winter refuse had a high ash content, sulphide was not produced. Water temperatures during this period never rose above 7°C. The success of winter tipping was considered to be due both to the depressant action of temperature on the rate of growth of the sulphate-reducing organisms and on the rate of oxidation of organic matter in the pit. Examination of samples of water drawn from nearby wells and pits indicated a dimishing salt concentration in the direction of underground water flow. The well half a mile down-stream from the pit showed a further small but steady rise in salt content but no change in its organic and bacterial quality.

The State Water Pollution Control Board of California (13) investigated the pollution of the ground water underlying a "cut and cover" type of refuse tip at Riverside, California. The composition of the refuse was not given but it was stated to be similar to domestic refuse from other U.S. cities except that it contained no cinders or ashes. The tip was 10 ft. thick and its bottom was just above ground water level. Leaching was considered to have occurred by intermittent contact with the ground water when this rose after rain. There was no evidence that precipitation had penetrated the tip and percolated into the ground water. A series of wells were bored both within and without the area of the tip, of which some were sited to determine the lateral and horizontal movement of polluting ions. The examination of samples of the ground water from the wells shows that the water under the tip had a maximum B.O.D. of 125 p.p.m., that the pollution travelled furthest in the direction of the ground water flow and that the quality of the water improved with increasing distance from the area of the tip. Under the conditions at Riverside, where the ground

water velocity was 4·9 ft. per day, the main effect half a mile down-stream from the tip was an increase in hardness. Anaerobic conditions existed in the tip one month after filling and the gas in the tip was then approximately 70 per cent methane and 30 per cent carbon dioxide. Field experiments were also conducted in which two wooden bins were filled with 7·5 ft. of household refuse, one being exposed to natural rainfall whilst the other received 20 galls. of water daily for three weeks until saturation occurred and then 20 galls. weekly. No percolate was obtained from the bin exposed to natural rainfall although 12·6-ins. had fallen in the 18-months test period. The second bin gave a percolate after the equivalent of 15-ins. of rain had been added in three weeks. The volume of percolate from the bin was one-third of the water added after the refuse became saturated, the difference in the absence of run-off was attributed to loss by evaporation. The B.O.D. of the percolate reached a maximum of 33,100 p.p.m. six weeks after saturation and then declined until at 12 months 98 per cent had been leached out. For the last six months the B.O.D. varied from 400 to 80 p.p.m. The maximum total hardness, alkalinity, chloride and sodium concentrations of the percolate were twenty times that of the unpolluted ground water. The ammoniacal nitrogen had a maximum of 890 p.p.m. and at the end of the experiment 240 p.p.m. were present. It was concluded that the introduction of refuse into exposed ground water or the movement of ground water through a dry refuse tip such as would occur when the ground water level rose after rain would result in serious mineral and organic pollution of the ground water in the vicinity of the tip.

The rate of travel of moderately polluted water through fine sand and the degree of purification achieved is quoted by Baars (14), Holland. At Leyden the public water supply is derived from the ground water in the dune area of Holland and of the 28-ins. of annual rainfall about 16-ins. is recovered from the collecting area. To meet increased demand and prevent the entry of brackish water, infiltration basins were constructed in the dune area and charged with polluted Rhine water. Although experimental work had indicated that the speed of infiltration in completely filled sandy soil was 35 ft. per day, calculated from Darcy's law (15), actual speeds at the infiltration basin were 12 to 16-ins. per day or less. This reduction was considered to be due to the resistance of the entrapped air. Dissolved oxygen is an important factor in the purification process and its maximum utilisation is achieved by a slow speed of travel with intermittent infiltration. Passage through 460 ft. of sandy soil of an infiltration water containing 100 to 200 *Escherichia coli* per millilitre gave an effluent in which *E. coli* was not detected in 100 mls. The effluent contained 0·08 p.p.m. of ammoniacal nitrogen, a trace of nitrate and no nitrite, whereas the infiltration water contained 3·1 p.p.m. of ammoniacal nitrogen and 6·2 p.p.m. of nitrate nitrogen.

Evaporation and Percolation

The proportion of rainfall that is subsequently available for domestic and industrial use is of cardinal importance to water engineers and others engaged in ensuring that adequate supplies of water are available for a community. In upland catchment areas, assessment is based on long-term records of stream gauges, water passed to supply, overflow and compensation water, together with the loss or gain in the storage reservoir. For rainfalls between 20-ins. and 80-ins. per annum the difference between the annual average rainfall and yield

is 17·3-ins. per annum according to the Interim Report of the Hydrological Committee of the Institution of Water Engineers (16). Lloyd (17) derived a formula for the evaporation loss from land areas by treating the soil water loss separately from that of the ground water. The annual soil water evaporation loss in inches was given by the equation—

$$\text{Loss} = 0{\cdot}57\ R^{0{\cdot}87} + 1{\cdot}10\ (T - 48) + 0{\cdot}006\ (S - 1{,}450),$$

where R is the rainfall in inches, T the mean air temperature in degrees Fahrenheit, and S the number of hours of sunshine per year. To the loss from the soil water was added the ground water evaporation loss which had a constant value varying from 0-in. for Cambrian rocks to 9-ins. for alluvial deposits and other highly permeable rocks.

For areas in Southern England where water supplies are mainly derived from underground water bearing strata the interest is in the proportion of rainfall that finally enters the aquifer and is available for abstraction for domestic and industrial use. From observations on percolation gauges, on fluctuations in the level of wells and in the flow of streams Lapworth (18) found, for formations in the chalk, that the annual percolation was primarily dependant on rainfall. A straight line $P = 0{\cdot}9\ R - 13{\cdot}5$ was obtained by plotting, for a number of sites, the annual average percolate P against the annual average rainfall R. The formula gives a percolate of 9·0-ins. and 13·5-ins. respectively for rainfalls of 25-ins. and 30-ins. per annum. Lapworth pointed out that the relation does not hold for individual years because the monthly distribution within the year has a great effect, i.e., most of the winter rainfall may enter the water table whereas in some months of summer little or no rainfall percolates to the water-bearing strata. The difference between the measured percolate of 14·9-ins. found for bare soil at Rothamsted compared with a calculated percolate of 10·1-ins., is attributed to the greater transpiration of grassland compared to bare soil.

The above attempts at relating percolate or evaporation with rainfall apply only to the long-term effect covering a period of several years. A different approach has been made by Penman (19), based on the energy changes involved in evaporation, which has proved more useful in predicting the more immediate effect of rainfall on the volume of percolate. Penman's formula for the evaporation from a free water surface is:

$$E_0 = 0{\cdot}35\ (1 + 9{\cdot}8 \times 10^{-3}\ u_2)\ (e_s - e_d)$$

where E_0 = evaporation from an open water surface in millimetres per day;

e_s = saturation vapour pressure at the temperature of the surface (mm. mercury);

e_d = saturation vapour pressure at the temperature of the dew-point (mm. mercury);

u_2 = mean horizontal velocity of the wind at a height of 2 metres above water level (miles per day).

Evaporation from any other surface E_s is related to that from free water by the formula $E_s = f \times E_0$ where f is a constant. The evaporation rate from a continuously wet bare soil is 0·9 times that from an open water surface exposed to the same conditions. For turf provided with a relatively plentiful supply of

water, the relative evaporation rate varies with the season of the year. For Southern England the following ratios are given:

	E Turf / E open water
November to February	0·6
March to April; September to October ..	0·7
May to August	0·8
Average for whole year	0·75

Annual evaporation from cropped land is considered to be less than from turf because there is less transpiration from annual crops during the ripening period. Assuming that the annual average factor for turf, viz. 0·75, can be applied to a catchment area Penman finds good agreement between the calculated evaporation rate for an open water surface with the observed values.

Catchment	Mean rainfall Minus run-off (R−r)	E_0 calculated $\frac{1\cdot0}{0\cdot75}$(R−r)	E_0 observed (nearby sites)
Lea	19·2	26	25; 26
Thames	18·7	25	24; 26
Severn	18·8	25	21; 24
Rivington ..	17·4	23	18; 21
Spey	10·3	14	17
Vyrnwy	19·1	26	21; 24

Makkink (20) determined the evaporation from turf using five lysimeters and compared the daily evaporation with that calculated from Penman's formula. The calculated values generally coincided with the lysimeter results but the variations were less pronounced. Over the whole period the evaporation from the lysimeters was 13 per cent greater than that calculated. Makkink relates this difference to the length of the grass which in his experiments was similar to pasture whereas the grass on Penman's lysimeters was cut like a lawn. Makkink concludes his paper by proposing a correction to the formula to allow for the increased turbulence due to the roughness of the grass surface.

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2. Preliminary Experiments on the Percolation of Water through House Refuse

These experiments were undertaken to provide information for the planning of the large pilot scale experiment to be undertaken at the site of an old disused sewage works at Bushey in Hertfordshire. The preliminary experiments took place in an open yard outside the laboratory, and their main objects were to discover how much of the applied water or natural rainfall would issue as percolate, and to determine the amount of chemical and bacteriological pollution acquired by the applied water and rainfall in its passage through the refuse. It was realised that an experiment on this small scale could not imitate the more natural conditions at Bushey; nevertheless, as it is unlikely that the experiment at Bushey could be readily repeated, any information likely to ensure its success was desirable.

The character of the refuse

The house refuse was supplied from residential districts in Watford with an average rateable value of £22 per year. The percentage composition of the refuse was as follows:

TABLE I

Refuse	Percentage by weight
(*a*) Fine dust content under ⅜-in. ..	16·62
(*b*) Small cinder content ⅜-in. to ¾-in. ..	10·19
(*c*) Large cinder content ¾-in. to 1½-in. ..	9·53
(*d*) Vegetable and putrescible content ..	26·03
(*e*) Paper content	18·12
(*f*) Metal content:	
Food containers	3·28
Other containers	0·54
Other metals	3·16
(*g*) Rag content	1·79
(*h*) Glass content (bottles and jars) ..	5·84
(*i*) Bone content	0·80
(*j*) Combustible debris	2·84
(*k*) Incombustible debris	1·26
	100·00

Experimental Procedure

Six drainpipes were assembled to give three lengths 6 ft. long by 1 ft. in diameter. About 3-ins. of gravel were placed at the bottom of each drainpipe to facilitate drainage. The drainpipe was then filled to within 3-ins. of its top with 4·7 cub. ft. of house refuse which was well compacted and covered with a few inches of soil. A rain gauge was fixed beside the top of the drainpipes and humidities were measured by wet and dry bulb thermometers. Thermometers were also inserted to a depth of about 9-ins. in the refuse.

The first drainpipe, subsequently referred to as Pipe 1, was saturated with distilled water at a rate just short of ponding, until an effluent was produced when the addition of water was stopped and the pipe allowed to drain for two days. The difference between the volumes of water added and that drained was taken as the saturation value of the refuse and was 17·5 litres, equivalent to 9·4-ins. of rain. Distilled water was subsequently added at the rate of 40 mls. every two hours throughout the working day, in all 200 mls. per day, equivalent to an annual rainfall of 30-ins.

To the second drainpipe (Pipe 2), 260 mls. were added every two hours without the preliminary saturation of the refuse given to Pipe 1. In all 1,300 mls. of water were added each working day and this corresponded to an annual rainfall of 197-ins.

The third drainpipe (Pipe 3) was exposed to natural rainfall only.

Volumes of percolate

Although the refuse in the Pipe 1 was saturated with water before the experiment began on 12th August, very little percolation took place during

August and September, 1953. There was a sharp increase in October, and in December 69 per cent of the added water appeared as percolate. The abnormally large percolate in February, 1954, was due to the release of water frozen in the refuse during the previous month. The lowest temperature recorded was −3·6°C. on the 1st February, 1954. The overall percolation for the experiment was 57 per cent.

The refuse in the Pipe 2 required over two weeks to become saturated, and the saturation value of 18·2 litres (9·8-ins.) was of the same order as that of the first pipe. After six weeks, the percentage percolation had reached 80 per cent, and on the 3rd October, 1953, the addition of water was stopped and the pipe allowed to drain for two days. Water was then added at the rate of 2,997 mls. per week, the corresponding equivalent of rain being 83-ins. per year. Percolation continued at a high rate and in January, 1954, the addition of water was stopped and the pipe exposed to natural rainfall.

In Pipe 3, exposed to rainfall only, no percolation took place for six months, but in February, 1954, 1,765 mls. of effluent were produced. The rainfall up to this period was 8·4-ins.; the saturation value of the refuse is probably somewhat greater than this figure implies because some rain falling on the flange of the pipe must have reached the refuse. If it can be assumed that nearly all the rain falling on the flange of the pipe reached the refuse the amount of water corresponding to 8·4-ins. of rain is 24·6 litres. This assumption has been made in calculating the figures given in Table II under Pipe 3. The volumes of percolate per month are given in Table II.

TABLE II

Volume of Percolate in the Drainpipe Experiment

Month	Pipe 1			Pipe 2			Pipe 3			
	Water added mls.	Percolate mls.	Per cent Percolate	Water or Rainfall added mls.	Percolate mls.	Per cent Percolate	Rainfall ins.	Rainfall mls.	Percolate mls.	Per cent Percolate
1953										
August ..	1,960	67	3·4	12,740	0	0	1·16	3,364	0	0
September..	4,320	204	4·7	26,780	15,853	59·2	1·96	5,684	0	0
October ..	5,400	1,871	34·6	17,188	13,019	75·7	2·37	6,873	0	0
November..	4,320	2,159	50·0	11,988	9,143	76·3	1·03	2,987	0	0
December..	3,920	2,704	69·0	10,878	5,755	52·9	0·30	871	0	0
1954										
January ..	5,200	2,537	48·8	8,254	2,157	26·1	1·13	3,264	0	0
February ..	4,320	6,708	155·3	5,845	9,677	165·6	2·02	5,845	1,765	30·2
March ..	4,320	1,997	46·2	4,162	2,057	49·4	1·44	4,162	2,750	66·1
April ..	3,800	1,854	48·8	1,914	0	0	0·66	1,914	320	16·7
May ..	5,400	3,793	70·2	4,888	22	0·5	1·69	4,888	201	4·1
June ..	3,960	2,659	67·1	8,410	5,460	64·9	2·90	8,410	5,840	69·4
July ..	5,400	3,186	59·0	6,322	3,261	51·6	2·18	6,322	2,745	43·4
August ..	4,120	2,566	62·3	10,414	8,865	85·1	3·59	10,414	8,319	79·9

Discussion on results on percolation

Percolation did not occur until the refuse was saturated with water and the time required for this varied with the rate and frequency of the addition of water. For example, in Pipe 2, the artificial addition of water equivalent to 197-ins. of rain per annum required two weeks, whilst under natural rainfall conditions with a much lower rate of addition and alternating periods of dry and wet weather the corresponding time was over five months. Once the saturation point was reached further rain then gave an effluent. In Pipe 1, where after saturation water was added regularly at a rate of 30-ins. per year, the percentage percolation, after the bed had stabilised, ignoring the abnormal February, was fairly constant at over 50 per cent. In Pipe 2, high rates of percolation were obtained at rainfalls of 197-ins. and 83-ins. per year, but, later, when the addition of water other than rainwater was stopped, the percolation corresponded with that of Pipe 3, which was exposed to natural rainfall.

Rainfalls corresponding to 197-ins. and 83-ins. per year are uncommon in this country, but although the percentage percolation was somewhat higher than that found in Pipe 1 with an applied rainfall of 30-ins. per year, the loss of water through evaporation seemed also to be higher. April and May were dry months and during this period when no other water was added, percolation was negligible. Later in the year the percentage percolation was considerable and in August, 1954, with its abnormally high rainfall, over 80 per cent percolation took place. The overall percolation was 57 per cent.

In Pipe 3, exposed to natural rainfall, percolation commenced in February, 1954. March, April and May were fairly dry months and the amount of effluent produced was small. Rainfall was abnormally high during the summer of 1954 and percolation also was high. Percolation lagged behind the rainfall and the refuse, already saturated with water, became super-saturated. The volume of percolate under these conditions then depended on the rate of drainage of the refuse and on evaporation. Since over five months were required to saturate the refuse, and the period when percolation took place was only seven months, it is a matter for conjecture what percentage of the rainfall falling on a saturated pipe would yield an effluent in a complete year. The overall figure for seven months was 53 per cent.

Evaporation from the drainpipes, which were exposed to atmospheric temperatures throughout their length as well as on their surface, cannot be assumed to be a guide as to that which would take place in a large-scale operation.

Chemical Examination of Percolates

The percolate from each of the three pipes was examined whenever sufficient volume was produced, but when the volumes were small, partial analysis only was possible. During the course of the experiments 153 chemical analyses were completed. Monthly averages of these results are given in Table III below and in Figures 1 and 2.

TABLE III

CHEMICAL ANALYSES OF THE PERCOLATES

Pipe 1—Initially saturated and then applied rainfall equivalent to 30-ins. of rain per year. Units parts per million.

Month	Free NH_3 N	Alb'd NH_3 N	Nitrite N	Nitrate N	Organic Nitrogen N	Organic Carbon C	P.V. 4 hrs. O	P.V. 3 mins. O	B.O.D.
1953									
August ..	127	140	0	10·7	233	5,800	2,440	740	13,500
September ..	34	86	—	6	117	1,520	830	230	—
October ..	14	74	91	27	117	1,990	820	340	—
November ..	450	145	0	5	167	6,700	825	330	12,500
December ..	490	102	2	10	111	4,490	710	249	7,660
1954									
January ..	560	88	4	13	101	4,200	690	250	7,050
February ..	470	86	2	9	95	2,920	620	230	4,350
March ..	195	61	39	18	75	820	510	180	204
April ..	80	43	130	23	55	710	600	290	156
May ..	17	31	79	207	41	480	385	154	93
June ..	4	22	9	240	33	380	283	97	36
July ..	3	19	1	255	41	350	270	100	28
August ..	3	11	6	227	27	410	246	97	40

Pipe 2—Water added equivalent to a rainfall of 197-ins. reduced in October to 83-ins. per year. After January, 1954, exposed to natural rainfall. Units parts per million

Month	Free NH_3 N	Alb'd NH_3 N	Nitrite N	Nitrate N	Organic Nitrogen N	Organic Carbon C	P.V. 4 hrs. O	P.V. 3 mins. O	B.O.D.
1953									
August ..	—	—	—	—	—	—	—	—	—
September ..	694	162	0	10	261	7,320	1,850	585	12,000
October ..	446	67	0	5	88	1,970	620	200	3,650
November ..	269	51	0	4	62	2,070	400	140	3,980
December ..	96	40	0	4	41	1,050	300	98	1,640
1954									
January ..	92	31	0·2	8	30	1,500	310	112	2,460
February ..	141	49	1·0	17	61	830	230	82	1,000
March ..	166	37	0·6	27	51	450	244	64	264
April ..	—	—	—	—	—	—	—	—	—
May ..	—	—	—	—	—	—	—	—	—
June ..	5	11	5	143	22	190	150	49	33
July ..	3	12	0·2	60	13	210	130	47	28
August ..	3	5	0	13	5	115	65	21	9

TABLE III—contd.

Pipe 3—Natural rainfall only

Month	Free NH_3 N	Alb'd NH_3 N	Nitrite N	Nitrate N	Organic Nitrogen N	Organic Carbon C	P.V. 4 hrs. O	P.V. 3 mins. O	B.O.D.
1953									
August ..	—	—	—	—	—	—	—	—	—
September ..	—	—	—	—	—	—	—	—	—
October ..	—	—	—	—	—	—	—	—	—
November ..	—	—	—	—	—	—	—	—	—
December ..	—	—	—	—	—	—	—	—	—
1954									
January ..	—	—	—	—	—	—	—	—	—
February ..	55	47	28	407	66	1,020	720	246	265
March ..	44	40	88	370	69	770	680	280	69
April ..	—	—	2	465	75	920	708	248	—
May ..	28	82	7	1,300	117	1,390	1,450	490	196
June ..	5	28	3	148	53	880	789	290	31
July ..	5	40	1	60	67	1,420	1,410	550	43
August ..	3	21	0·1	13	30	1,000	885	308	34

The initial percolates from Pipes 1 and 2 were extremely strong liquors with a B.O.D. of 12,000 p.p.m. compared with that of crude domestic sewage with a B.O.D. of about 400 p.p.m. Further, they contained only a negligible amount of oxidised nitrogen. Pipe 3, exposed to natural rainfall gave no percolate for six months and then gave a percolate with a B.O.D. of 265 p.p.m. and 407 p.p.m. of nitrate nitrogen. As judged by these two criteria, it was a far better quality effluent than that obtained initially from the two other pipes which had given percolates for six months. Figure 2.1 shows the production and loss of ammonia followed by formation of nitrite which in turn was replaced by nitrate. It will be noted in Pipe 3 that nitrification had proceeded to the nitrate stage before an effluent was produced.

Figure 2.2 shows that the B.O.D's. of the effluents in Pipes 1 and 2 had reached a comparatively low level by March, 1954, and that the effluent from Pipe 3 commenced at this level. From March until the end of the experiment the three B.O.D's. coincided and fell gradually. The organic carbon also decreased, but here higher levels were obtained in Pipe 3 and it would appear that organic matter was present which responded to chemical but not to biological oxidation. This to a lesser extent also applies to the effluent from Pipes 1 and 2 where the ratio of the B.O.D. to the permanganate value was reversed in the second half of the year.

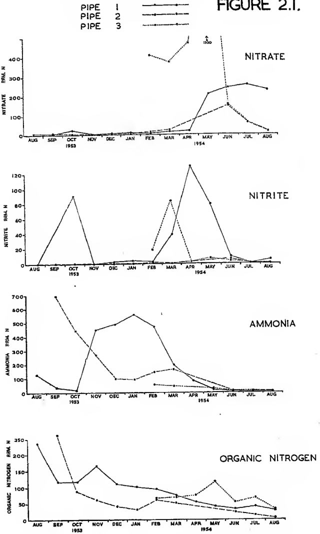
The *p*H of the percolate from all three pipes tended to increase during the course of the experiment, and at the end the values were 9·3, 8·6 and 9·4 for Pipes 1, 2, and 3, respectively.

Discussion of the Chemical Data

At the end of the experiment the B.O.D's. of the percolates from the three pipes were between 10 and 40 p.p.m. The percolates still contained considerable amounts of organic matter in solution, and the organic carbon, which is a

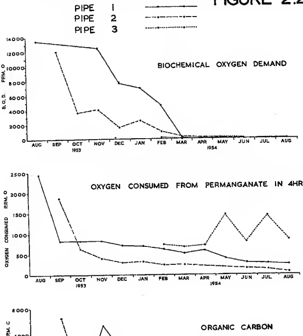
PIPE EXPERIMENTS

FIGURE 2.1.



PIPE EXPERIMENTS

FIGURE 2.2.



E

measure of the total organic matter, remained relatively high at 410, 115 and 1,000 p.p.m. as carbon in Pipes 1, 2 and 3, respectively. At this stage, the permanganate values, which measures that part of the total organic matter which readily undergoes chemical oxidations, were also high, with values of 246, 65 and 885 p.p.m., respectively, for Pipes 1, 2 and 3. During the last six months of the experiment the ratio of the organic carbon to the difference between the 4 hours and 3 minutes permanganate values, had fallen from high initial figures to a relatively constant value which averaged 2·3 for Pipes 1 and 2, and 1·75 for Pipe 3.

It is a controversial point whether an effluent containing organic matter intractable to biological but susceptible to chemical oxidation should be discharged to ground water, and the answer must depend on whether this intractable organic matter will eventually break down to give compounds which will respond to further biological oxidation. The organic nitrogen bodies appeared to be broken down more rapidly and more completely than the carbon compounds and the virtual completion of nitrification is confirmatory.

Sulphates and sulphides were determined in the effluents and the results show that original concentrations of 7,300, 4,720 and 3,730 p.p.m. SO_4 in Pipes 1, 2 and 3, respectively, fell to 550, 270 and 150 p.p.m. SO_4. This reduction in concentration was continuous except for a slight increase in March in Pipe 1, in February in Pipe 2, and a fairly large progressive increase up to the end of May in Pipe 3. A little sulphide was produced at the beginning of the experiments, but this stopped and there was no evidence of the reduction of sulphate to sulphide.

The Bacteriological Examination of the Percolates

The methods used in the bacteriological examination of the percolates from the three Pipes are given in the Appendix. The results of the examination expressed as monthly averages of the weekly counts are given in Table IV below.

TABLE IV

Numbers per ml. of organisms growing on MacConkey Agar at 37°C.
(monthly average)

Month	Pipe 1	Pipe 2	Pipe 3
1953			
August	$17{,}000 \times 10^4$	—	—
September	55×10^4	$3{,}400 \times 10^4$	—
October	560×10^4	170×10^4	—
November	20×10^4	95×10^4	—
December	15×10^4	100×10^4	—
1954			
January	10×10^4	35×10^4	—
February	10×10^4	45×10^4	270×10^4
March	20×10^4	100×10^4	10×10^4
April	25×10^4	—	5×10^4
May	25×10^4	—	40×10^4
June	8×10^4	6×10^4	20×10^4
July	8×10^4	10×10^4	50×10^4
August	20×10^4	1×10^4	10×10^4

Number per ml. of organisms growing on MacConkey Agar at 44°C. (monthly average)

Month	Pipe 1	Pipe 2	Pipe 3
1953			
August	30,000,000	—	—
September	2,500	1,000,000	—
October	400	2,200	—
November	40	550	—
December	60	180	—
1954			
January	10	20	—
February	300	2,100	400
March	20	250	350
April	10	—	6
May	80	—	5
June	30	40	10
July	70	3	400
August	10	4	150

Number per ml. of faecal streptococci (monthly average)

Month	Pipe 1	Pipe 2	Pipe 3
1953			
August	2,000,000	—	—
September	1,600	300,000	—
October	310	1,900	—
November	80	500	—
December	60	90	—
1954			
January	30	40	—
February	260	3,500	650
March	150	450	650
April	70	—	6
May	80	—	1
June	10	100	20
July	50	0	30
August	40	0	30

Discussion of Bacteriological Counts

It will be noted that very high counts were obtained initially in Pipes 1 and 2, being of the order of millions per ml. At the end of six weeks both *Escherichia coli–I* and faecal streptococci were reduced in numbers to approximately a thousand. At this stage the numbers of coliform bacteria began to increase and at the same time mixed cultures appeared on the roll-tubes. MacConkey agar incubated at 37°C. apart from showing coliform bacteria developed large numbers of bacteria which on differential tests did not conform to the known characteristics of coliform bacteria.

After six weeks, typical colonies of *E. coli–I* were present on MacConkey agar incubated at 44°C., but in addition atypical colonies appeared which on test were classified as *E. coli–II*, *E. coli–III*, *Irregular–2* and *–5*, *Intermediate–1* and *Bact. aerogenes–I*. *E. coli–I* was not found towards the end of October nor in November and December. It was found once in January and later in one sample taken in June, but for all practical purposes it disappeared after 10 weeks.

In Pipe 3, the initial counts started at a much lower level. Here *E. coli–I* and faecal *streptococci* appear at a level of about 1,000 per ml. and after five weeks dropped to about 100 per ml. After this period mixed cultures of coliform bacteria appeared at 44°C., but *E. coli–I* virtually disappeared. Faecal *streptococci* were not confirmed after April in Pipe 3.

Because of the production of mixed colonies as the experiment proceeded, the data is difficult to interpret, but it appeared that *E. coli* died out in about 10 weeks and that the decline of faecal *streptococci* was similar in the early stages, but they appeared to persist for a longer time than *E. coli*–I. In Pipe 3, under conditions of natural rain, lower numbers of these bacteria grew and the decline was such that in a few weeks relatively few remained.

Summary

1. No percolation occurred until after the refuse was saturated with water. Water equivalent to 9·4-ins. of rainfall was required to saturate the refuse when artificially added, and slightly more than 8·4-ins. of rainfall were required under natural conditions of precipitation.

2. After saturation the amount of percolate was 50 per cent of the added water. In the pipe under conditions of natural rainfall the volume of percolate varied from 4 to 69 per cent of the rainfall with an average percolation of 53 per cent.

3. Once percolation had started the onset of a dry period caused little lag in the flow of percolate when further rainfall occurred.

4. No heating of the refuse occurred, and no correlation was detected between the amount of percolate and either the humidity or temperature of the air.

5. The strengths of the percolates first produced from pipes to which water was added artificially were thirty times that of raw domestic sewage, and gave high counts of *E. coli–I* and faecal *streptococci*. Percolation for one year was necessary before the strengths of the percolates approached that of the standard recommended for a sewage effluent by the Royal Commission on the Disposal of Sewage.

6. Exposure for almost six months was necessary before the pipe under natural conditions of rainfall gave a percolate. The strength of this percolate was very much less than that of the initial percolates from the pipes to which water had been artificially added. It was similar in character to the percolates produced at the same time from the other pipes but, unlike the artificially produced percolates, it was highly nitrified. Aerobic conditions prevailed throughout the drainpipe experiments.

3. Percolation of Water through House Refuse (pilot plant scale)

INTRODUCTION

Preliminary experiments to assess the effect of rain falling on house refuse tipped in a dry pit have been described. These were carried out on a small scale using drainpipes to represent the dry pit and showed that a percolate was produced after the refuse was saturated with water. This percolate was heavily polluted, both with organic matter and with bacteria, and the experiment was continued until a relatively unpolluted percolate, which would be unlikely to affect underground water supplies, was obtained.

These experiments gave useful information, but it was essential to compare the results with those obtained on a much larger scale. If nothing else, the drain-pipe experiments had given data upon which the larger scale experiment could be planned with some confidence.

The primary objectives of the experiment were:

(1) to measure the volume of the percolate from a dry tip and to determine its variation with rainfall, temperature and humidity;

(2) to determine the chemical composition and bacteriological quality of the percolate;

(3) to assess the degree of pollution likely to be imparted to the ground water and how this varied with the age of the tip.

Description of the pit

The experimental dry pit was one of several sedimentation tanks at a disused sewage works at Bushey. It was rectangular in shape with sides of 42 ft. and 35 ft. and had an average depth of 5¼ ft. The tank was lined with an impervious blue brick and the only adaptation needed for its use for experimental purposes was the raising of the sides above ground level to prevent the ingress or egress of surface water. The walls were raised 18-ins., thus increasing the average depth of the tank to 6¾ ft., and concrete ramps were constructed on two sides to facilitate the tipping of refuse into the tank.

The bottom of the tank sloped downwards and away from three sides towards a drainage outlet at the centre and bottom of the fourth side. A 1-in. bore alkathene tube was fitted to the drainage outlet which carried percolate to a 300-gall. collecting cistern placed at a lower level in an adjacent unused sludge tank.

The filling of the tank

The bottom of the tank was first covered to a depth of 9-ins. with a layer of coarse clinker, graded 3 to 6-ins., to allow any percolate produced a free run-off to the collecting cistern. This was considered necessary for two reasons. Firstly, rainfall and percolate produced could then be related and, secondly, analyses of the percolate with its load of organic matter and bacteria could be carried out without delay to obtain a true picture of its composition. House refuse was tipped into the pit on the 14th June, 1954, and tipping was completed on the 30th June, 1954, when 49 loads weighing 90 tons had been added. The refuse was compacted by a mechanical vibrating roller to a final depth of approximately 5 ft., giving a bulk density of 7·8 cwt. per cub. yd.

The refuse was finally covered to a depth of 18-ins. with soil obtained from a field formerly used for sludge disposal but which had not been used for this purpose for many years. About 80 cub. yds. of soil were needed and the work was completed on the 1st July, 1954.

When a section of the tip was opened towards the end of the experiment (page 78) the depth of soil cover at the centre was 30-ins. and the total thickness of the refuse was 40-ins. Considerable settling had thus occurred and the bulk density had increased to 9·2 cwts. per cub. yd. During the period of filling the rainfall was slight, only 0·17-ins. being recorded. The amount of refuse in the pit represented the average collection from about 9,000 people for a period of two weeks.

The composition of the refuse

The refuse consisted of house refuse collected from houses in Watford of an average annual rateable value of *£22 per annum*, and transported directly to the experimental pit. There was no separate collection of waste food in operation at the time. The refuse contained no trade waste and it had not been through a sorting plant for the recovery of salvage. A half-ton sample of the refuse was separated into its main constituents and each lot weighed. The composition of the refuse is given in Table I.

TABLE I

Composition of house refuse—June, 1954

Material	Percentage
(*a*) Fine dust content, under ⅜-in. ..	18·65
(*b*) Small cinder content, ⅜-in. to ¾-in. ..	8·56
(*c*) Large cinder content, ¾-in. to 1½-in. ..	5·41
(*d*) Vegetable and putrescible content ..	24·91
(*e*) Paper content	20·82
(*f*) Metal content:	
Food Containers	4·45
Other Containers	1·59
Other Metals	0·84
(*g*) Rag content	2·14
(*h*) Glass content	8·44
(*i*) Bone content	0·26
(*j*) Non-combustible debris	1·51
	100·0

The refuse being collected in June had a relatively high content of vegetable and putrescible matter, and low content of cinders and fine dust; it was regarded as a typical summer house refuse.

Because of its heterogeneous nature it was impracticable to obtain a representative sample of the refuse for chemical analysis. It was possible, however, to prepare water extracts of each grade of material in the refuse and thus to determine the proportion of polluting substances that could readily be leached from the refuse as a whole. Such extracts were later prepared from the summer refuse used to fill the wet tip (see Table VIII in Chapter 6) and when these values were applied to the refuse described in Table I used to fill the dry tip the following results were obtained:

TABLE II

Water soluble portion of the refuse

	Per ton	Total in pit (90 tons)
Permanganate value:		
30 mins.	2·6 lb. (1·2 kilos)	235 lb. (107 kilos)
4 hours	4·2 lb. (1·9 kilos)	378 lb. (172 kilos)
Chloride, Cl	2·2 lb. (0·97 kilos)	195 lb. (88·5 kilos)
Ammonia, N	0·31 lb. (0·14 kilos)	28 lb. (12·7 kilos)

Estimation of the total polluting matter in fresh house refuse

While all the fractions of house refuse contribute a quota to the total amount of pollution, the major sources are the fine dust, the paper and board, the rags and the vegetable matter. An analysis of the fine dust is given in Table III while that for paper and board and for rags may be taken from the reference books on these materials without introducing any considerable error.

TABLE III

Analysis of the Fine Dust Fractions of the Refuse

(On sample as received) Mean of two analyses	Per cent
Moisture at 105°C.	17·2
Loss on ignition	22·6
Silica	45·5
Calcium oxide	3·9
Magnesium oxide	0·2
Iron and aluminium oxides	6·7
Sulphate as SO_3	2·2
Phosphate as P_2O_5	0·5
	98·8
Fat and grease	0·86
Sulphide	225 p.p.m.
	Per cent
Organic carbon	14·6
Organic nitrogen	0·45

The carbon and nitrogen content of the vegetable and putrescible fraction was not known and because of its heterogeneous nature it was impossible to obtain a representative sample suitable for analysis. It was therefore considered that if the weights of the separate ingredients in this fraction of freshly-collected refuse were accurately known it should be possible to estimate the percentage of carbon and nitrogen using the tables given in "The Chemical Composition of Foods" by McCance and Widdowson and those in "Rations for Livestock". Freshly-collected refuse delivered in August to the site at Bushey for tipping into the wet pit was divided into halves and from one half of approximately 25 cwt. the vegetable and putrescible matter was hand-picked and sorted into similar types of material and each type weighed. From this data it was estimated that the vegetable and putrescible fraction contained 7·56 per cent of carbon and 0·66 per cent of nitrogen.

On this basis an approximate estimate of the carbon and nitrogen in the 90 tons of refuse in the dry pit has been made and is given in Table IV.

TABLE IV

Estimation of carbon and nitrogen in 90 tons of house refuse

Fraction of Refuse	Percentage in Refuse	Percentage Moisture	Percentage Composition		Percentage of Carbon and Nitrogen in Refuse		Total amount in Refuse in Pit lb. (Kilos)	
			C	N	C	N	C	N
Vegetable and putrescible	24·9	85	7·56	0·66	1·88	0·164	3,760 (1,710)	328 (149)
Paper and Board ..	20·8	8	40·9	0·01	8·51	0·002	17,000 (7,740)	4 (1·8)
Rags	2·14	10	40·0	0·01	0·85	0·0002	1,700 (770)	0·4 (0·2)
Fine dust ..	18·65	—	14·6	0·45	2·72	0·084	5,450 (2,480)	168 (76)
TOTAL ..	66·50	—	—	—	13·96	0·250	27,910 (12,700)	500 (227)

A proportion of the carbon in the fine dust was derived from unburnt solid fuel and cinders and this would contribute but little to the pollution from a refuse tip. Some of the other carbon compounds would be water-soluble and some might become water-soluble after putrefactive changes had taken place. The figure for total carbon therefore will not indicate that which would eventually be leached out by water, nor would a figure which took account only of the carbon in the fresh dust that was soluble in water. The water-soluble carbon and nitrogen contents of the fine dust fraction of the refuse used to fill the dry tip were 0·43 per cent and 0·03 per cent, respectively, and if these figures were used in Table IV the total carbon in the 90 tons of refuse would be 10,292 kilos and the nitrogen 157 kilos. The actual content from the pollution aspect will be somewhere between these figures and those given in Table IV.

PERCOLATION OF WATER THROUGH THE REFUSE

A. PHYSICAL DATA

(1) *Rainfall and the volume of percolate*

The monthly rainfalls and volumes of percolate are given in Table V and Figure 3.1. Column 7 of the table gives the volume of percolate expressed as a percentage of the rainfall.

(2) *Air and refuse temperatures*

Mean monthly air and refuse temperatures have been calculated from the daily, 10 a.m. observations. The temperature of the refuse was taken at a depth of 4 ft. The figures are given in Table V and Figure 3.2.

(3) *Relative humidity*

The mean monthly value is given in Table V and Figure 3.2.

TABLE V

Physical data

(Monthly totals and means)

Month	Mean temperature 4 ft. from surface °F	Mean air temperature °F at 10 a.m.	Mean rel. humidity at 10 a.m.	Total rainfall		Total percolation litres	Per cent percolation
				inches	litres		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1954							
June	159	63	72	0·17	590	0	0
July	112	62	74	2·22	7,703	53·7	0·7
August ..	81	62	83	2·30	7,981	295	3·7
September ..	77	58	81	1·25	4,337	31·3	0·7
October ..	76	58	81	1·74	6,037	410	6·8
November ..	67	48	87	4·26	14,782	6,719	45·4
December ..	70	46	85	1·462	5,073	5,131	101
1955							
January ..	57	37	88	2·124	7,370	5,619	76·2
February ..	51	38	91	1·34	4,640	3,397	73·2
March	50	42	71	0·79	2,743	1,440	52·4
April	52	53	72	0·54	1,911	842	44·1
May	64	54	71	4·0	13,880	3,466	25·0
June	55	62	77	2·00	6,950	1,563	22·5
July	58	66	71	0·51	1,752	567	32·3
August ..	63	66	80	1·06	3,679	687	18·7
September ..	62	60	80	1·385	4,806	540	11·2
October ..	60	52	84	4·07	14,094	4,300	30·5
November ..	54	47	88	2·25	7,808	4,399	56·3
December ..	72	44	90	2·235	7,758	3,503	45·2
1956							
January ..	71	39	92	4·155	14,422	10,537	73·1
February ..	64	33	86	0·28	958	3,740	390·4
March	61	46	77	0·92	3,191	1,454	45·6
April	59	49	70	1·055	3,505	869	24·8
May	61	59	69	0·325	1,129	401	35·5
June	69	59	78	2·27	3,785	744	9·6
July	71	64	81	3·415	11,847	1,827	15·4
August ..	73	59	83	5·150	17,869	3,421	19·1
September ..	67	59	88	2·625	9,110	4,030	44·2
October ..	75	53	86	2·715	9,419	4,597	48·8
November ..	67	44	90	0·490	1,699	526	31·0
December ..	65	44	96	3·695	12,823	5,582+	44 +
1957							
January ..	65	44	89	1·345	4,674	4,435	94·9
February ..	65	46	89	3·960	13,748	10,354+	75 +

DISCUSSION OF RESULTS

Rainfall and Percolation

The summer of 1954, after the pit was filled, was wet, and by the end of September, 5·94-ins. of rain fell on the refuse. Thus the incidence of rain at

the commencement of the experiment when drier conditions might have been expected, was heavy, and as a result saturation of the refuse took place quickly without a preliminary dry period during which a measure of purification, such as occurred in the drainpipe experiment, might have taken place.

In the period of July to December, 1954, 13·23-ins. of rain fell; the total for the first year, July, 1954, to June, 1955, being 24·03-ins., of which 4·25-ins. fell in November, 1954, and 4-ins. in May, 1955. The total rainfall during the year July, 1955, to June, 1956, was 20·51-ins.; the summer of 1955 was dry, and in the three months July to September only 2·95-ins. of rain fell. October, 1955, and January, 1956, were wet months, each having over 4-ins. of rain.

A small volume of liquid from the dry tip was produced within two weeks, and during July more liquid was collected though still in small quantities. Its incidence appeared to coincide with that of rainfall but, nevertheless, it represented only a very small fraction of the total volume of rain that had fallen on the pit during this period.

Early in August two trial holes were dug in the centre of the tip and it was quite evident that the refuse was not saturated with water. It was somewhat similar to that such as is found in a compost bed, and was steaming slightly. The liquid collected during this period and for some time after could not be classified as percolate, and was in fact derived from the refuse itself, by a process somewhat akin to distillation during the initial heating of the refuse.

Towards the end of October, the amount of percolate showed a sharp increase and Table V shows that in November, 45 per cent of the rainfall was being collected in the cistern receiving the drainage from the tip. The total amount of rain absorbed by the refuse up to the time when percolation really commenced in November was 7·3-ins., and this is similar to the saturation values found in the preliminary drainpipe experiments.

In order to confirm that the refuse was saturated and that the liquid produced was a true percolate and not the result of rain seeping down the sides of the tank enclosing the tip or channelling through the refuse, conductivity measurements were made. The electrode used consisted of a steel rod, 7 ft. long; one end about 6-ins. long was fashioned as a drill and this drill was electrically insulated from the rest of the rod, the resistance between the two portions of the rod being a measure of the conductivity.

Readings were taken at 21 positions covering the entire area at different depths, and an average reading at different depths is given below:

Depth feet	Resistance ohms
½	221
1	135
1½	106
2	86
2½	45
3	49
3½	60
4	125
4½	736

RAINFALL & PERCOLATION

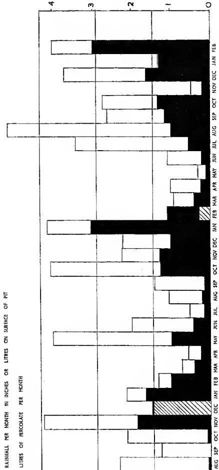


FIGURE 3.1.

MONTHLY MEAN VALUES OF TEMPERATURE & HUMIDITY

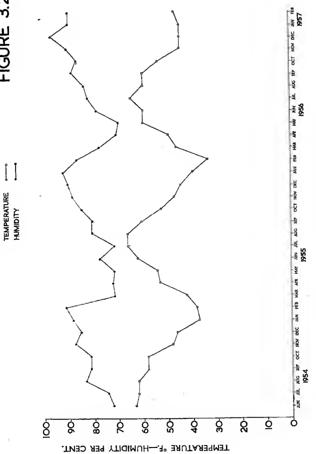


FIGURE 3.2.

These results indicate that while there was some surface drying out and drier conditions below 4 ft., the refuse was wet and the effluent was in fact a true percolate.

Figure 3.1 gives a picture of the relationship between rainfall and percolation, and illustrates the difference between winter and summer conditions. Under natural conditions, rainfall is intermittent, allowing a drying-out of the surface of the refuse tip between showers. In summer, with less rain and greater evaporation, the amount of percolate produced was smaller than in winter, but it never ceased completely. In this experiment, loss of rain falling on the refuse was by evaporation only; there was no run-off and consequently the amount of percolate produced in a natural site would be smaller to the extent to which run-off occurs.

In the experimental site at Bushey where no run-off was possible the following table gives the loss of rainfall due to evaporation and to percolation.

TABLE VI

Period	Rainfall	Percolate	Evaporate and Transpirate
	ins.	ins.	ins.
July, 1954, to June, 1955 ..	24·03	8·34	15·69
July, 1955, to June, 1956 ..	20·51	9·13	11·38
July, 1956, to February, 1957	23·40	10·02	13·38

It is understood that Penman for the Bushey–Watford area gives a figure of 18-ins. per year for evaporation and transpiration; if this figure is accepted, it would appear that refuse is more permeable than pastural land, and that the amount of percolate is about 6-ins. greater than the normal.

The refuse at Bushey was compacted by a mechanical vibrating roller, but in comparison with normal practice when a bulldozer is used, the degree of compaction would be smaller and the permeability greater. As a result the percolate at Bushey would be expected to be greater than that at a natural site. The figure of 8·34-ins. total percolate in 1954–55 might well be reduced to the order of 4-ins., or about 17 per cent, instead of 35 per cent of the rainfall.

The refuse pit at Bushey rapidly became covered with grass and weeds, and at no time, even during torrential rain, was any ponding observed such as may be seen on natural sites covered with refuse. This also points to a penetration greater than normal, but nevertheless, when assessing the danger to underground water it would be wise to take the amount of percolate at what is considered an outside figure, and one that will not arise unless under exceptional circumstances. The extension of this work to a natural site where the risks involved could be more certainly ascertained is worth serious consideration.

The total volumes of percolate obtained throughout the experiment from the rainfall on an area of 1,470 sq. ft. of refuse with a depth of about 5 ft. (about 90 tons of refuse) is given in Table VII.

TABLE VII

Total volume of percolate from the Dry Tip

Period	Percolate Gallons
14th June, 1954, to December, 1954 ..	2,780
January, 1955, to June, 1955	3,592
July, 1955, to December, 1955	3,079
January, 1956, to June, 1956	3,904
July, 1956, to December, 1956	4,396
January, 1957, to February, 1957 ..	3,254
TOTAL ..	21,005

Air and Refuse Temperatures

The mean temperature of the refuse was 154°F. on 1st July, 1954, the day after tipping was completed and the refuse consolidated. This temperature was maintained for 11 days, and then slowly fell, reaching a mean value of 80°F. in August and 70°F. in December. In December, 1954, and January, 1955, there was a rapid fall of 15°F. in the refuse temperature, but owing to the cold weather the significance of this was not realised at the time. Subsequently, it was found that the rototherm was reading 15°F. lower than the true reading and from January until December, 1955, the temperatures of the refuse have been corrected by the addition of 15°F. to the recorded reading. In December, 1955, a new thermistor was installed and from then on the actual readings were used to calculate the mean monthly temperature.

After the initial heating and decline in the temperature of the refuse, the pit temperature followed the same seasonal trend as the air temperature for the duration of the experiment, but at a level between 15°F. and 20°F. higher.

Relative Humidity

The relative humidity of the air followed a seasonal pattern being low in the summer and high in the winter. In combination with air movement and air temperature, relative humidity is a factor in controlling the evaporation of water from the surface of the tip, and their combined effect is shown by the reduced percolate in summer when expressed as a percentage of the rainfall. It was not possible to determine the effect relative humidity by itself had on the flow of percolate.

B. THE CHEMICAL QUALITY OF THE PERCOLATE

All the samples of percolate were taken to the laboratory for examination and the following determinations carried out.

Ammoniacal and albuminoid nitrogen, nitrite and nitrate, organic nitrogen, organic carbon, permanganate value at 80°F. (3 minutes and 4 hours), B.O.D. at 65°F., sulphate, sulphide, *p*H and after January, 1955, chloride.

The chemical determinations were designed not only to measure the strength of the percolate in terms of its ability to pollute underground water but also to gain some insight into the purification changes taking place within the refuse itself. The chemical results, as monthly averages are given in Table VIII.

Perhaps the two best guides as to the strength are the B.O.D. and the permanganate values, being measurements of the oxygen necessary for removal of readily oxidisable polluting substances biologically and chemically respectively.

Biochemical oxygen demand (Table VIII and Figure 3.3)

The maximum strength of 7,745 p.p.m. was reached in December, 1954, two months after a true percolate appeared. The percolate was thus about 19 times stronger than the crude domestic sewage of a town of mixed industry with a B.O.D. of about 400 p.p.m. After this the value for the B.O.D. showed a downward trend and the mean value for September, 1955, was 163 p.p.m. Heavy rain in June and November, 1955, and in January, 1956, apparently washed out an accumulation of pollution, probably in the clinker drainage bed underlying the refuse, and maximum figures of 3,965, 1,794 and 1,008 p.p.m., respectively, were recorded during these months. It would appear that the rain removed most of the polluting material giving a high B.O.D. for subsequently, in March, 1956, the B.O.D. fell to 55 p.p.m. and in July, 1956, notwithstanding a rainfall of 3·41-ins. and a percolate of 1,827 litres, the B.O.D. was only 38 p.p.m. During the autumn and winter the fall in the B.O.D. was slower and in February, 1955, the B.O.D. was 18 p.p.m.

These figures indicate that the bulk of the pollution as measured by the B.O.D. was removed from the refuse by September, 1955, or about 14 months after the commencement of tipping; the corresponding period in the drainpipe experiments was 12 months and it will be remembered that decomposition and destruction of putrefactive matter giving a B.O.D. took place at approximately the same rate whether water was or was not added to the refuse in the pipes.

Permanganate Value (4 hours N/80 permanganate) (Table VIII, Figure 3.3)

The permanganate value of the percolate reached a maximum of 885 p.p.m. in December, 1954, and thereafter declined. The important difference is that whereas the B.O.D. was lost rapidly and in July, 1955, had reached a figure approaching the Royal Commission Standard for sewage effluents, the permanganate value fell slowly and in July, 1956, the high value of 160 p.p.m. remained. At the conclusion of the experiment in February, 1957, the permanganate value had fallen to 79.

It is evident that organic matter was present in the percolate which responded to chemical but not biological oxidation and it will be remembered that this was found also in the drainpipe experiments.

Organic Carbon and Organic Nitrogen (Table VIII, Figure 3.3)

These behaved like the B.O.D. and permanganate values in that they increased to their maxima in December, 1954, and then declined. The rate of decline of organic carbon was similar to that of the B.O.D. until February, 1956, but after that it slowed up and in February, 1957, there remained 176 p.p.m. Organic nitrogen was lost steadily but slowly, and the trend with time was similar to that of the permanganate values. The reductions from maximum to minimum values was 27/fold in the case of organic carbon and 15/fold for organic nitrogen, suggesting that organic carbon compounds were being broken down more quickly than organic nitrogen bodies. Some idea of the nature of the organic carbon compounds can be obtained by considering the ratios of the permanganate values, which are measures of the readily oxidisable organic

TABLE VIII

PERCOLATE FROM THE DRY TIP

Chemical results monthly mean values

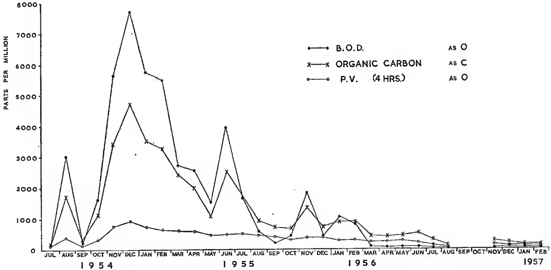
parts per million

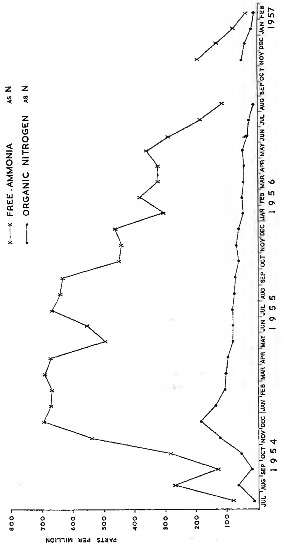
No. of samples examined	Month	Ammoniacal Nitrogen N 1	Albuminoid Nitrogen N 2	Nitrite N 3	Nitrate N 4	Organic Nitrogen N 5	Organic Carbon C 6	B.O.D. (65°F) 7	Permanganate value 4 hrs. 8	Permanganate value 3 mins. 9	Sulphate SO_4 10	Sulphide S 11	pH 12	Chloride Cl 13
	1954													
5	July	78	8·8	3·02	57·8	10·8	125	125	80	29	539	4	7·1	—
5	Aug.	265	44	0	28·5	61	1,694	3,028	351	119	441	7·9	7·2	—
4	Sept.	127	15·3	0·04	37·0	19	314	200	87	27	427	6·0	7·6	—
3	Oct.	289	47·2	0	23·3	51·4	1,110	1,605	275	90	1,146	2·4	7·4	—
10	Nov.	537	101	0·05	0	120·1	3,380	5,645	710	218	1,423	11·7	7·1	—
8	Dec.	694	144	0	0	182·2	4,710	7,745	885	285	1,321	21·5	7·1	—
	1955													
9	Jan.	670	103	0	0	132	3,470	5,767	687	239	898	28·4	7·3	—
8	Feb.	668	71	0	0	101	3,244	5,491	600	215	248	26·2	7·4	1,845
9	Mar.	687	79	0	0	100	2,400	2,689	587	206	738	28·6	7·5	1,968
7	Apr.	668	71	0	0	94	1,958	2,534	560	196	231	26·0	7·6	1,987
8	May	496	61	0	0	77	1,055	1,152	415	141	323	13·9	7·5	1,629
9	June	553	56	0	0	77	2,494	3,965	436	151	2·2	14·1	7·3	1,577
8	July	664	65	0	0	81	1,675	1,624	463	162	3·2	9·5	7·4	1,887
9	Aug.	637	62	0	0	75	907	526	421	150	4·2	8·2	7·6	1,830
9	Sept.	630	59	0	0	71	686	163	368	125	71·8	3·1	7·9	1,874
9	Oct.	447	48	0·07	0	60	666	397	271	93	133	2·4	7·7	1,389
10	Nov.	441	50	0	0	67	1,325	1,794	324	107	80	9·5	7·4	1,438
4	Dec.	458	47	0·10	0	59	678	396	323	100	606	4·5	7·6	1,710

	1956													
5	Jan.	302	36	0	0	44	860	1,008	224	73	380	17·0	7·4	1,438
4	Feb.	379	42	0	0	50	844	764	261	86	816	17·8	7·4	1,386
4	Mar.	320	32	0	0	42	394	55	204	67	1,826	2·8	7·3	1,382
4	Apr.	322	32	0	0	41	381	44	242	79	1,602	4·0	7·4	1,440
5	May	355	36	0·02	0	50	467	56	271	98	856	4·2	7·7	1,763
3	June	286	31	0·02	0	36	527	51	247	79	512	4·4	7·8	1,407
5	July	187	22	0·04	0	28	341	38	160	57	81	2·4	8·0	1,407
3	Aug.	110	12	0·12	0	15	161	15	92	37	98	1·3	7·9	622
4	Nov.	189	29	0·34	0	49	283	12	163	58	1,344	2·0	8·0	1,357
4	Dec.	129	23	0·20	0	40	251	47	132	41	1,266	4·6	7·8	1,100
	1957													
4	Jan.	77	15	0·03	0	18	170	25	107	38	1,334	4·6	7·7	853
4	Feb.	42	9	0·05	0	12	176	18	79	29	930	1·8	7·1	573
183														

FIGURE 3.3.

MONTHLY MEAN CONCENTRATIONS




FREE-AMMONIA AS N
ORGANIC NITROGEN AS N
PARTS PER MILLION
800
700
600
500
400
300
200
100
JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB
1954
1955
1956
1957

matter, and the organic carbon figures which include all the oxidisable organic matter. In a like manner the ratio of the albuminoid nitrogen to the total organic nitrogen can be used for the organic nitrogen bodies. These ratios did not alter much with time; organic carbon showed a greater stability than organic nitrogen compounds, and until March, 1956, only about 10 per cent of the total responded to oxidation by permanganate under the conditions of that test. After March, 1956, about 20 per cent were oxidised by permanganate. Organic nitrogen compounds were more tractable, and 70 to 80 per cent appeared as albuminoid ammonia, that is, they were susceptible to oxidation by boiling alkaline permanganate.

Ammoniacal, Nitrous and Nitrate Nitrogen (Table VIII, Figure 3.3)

Ammoniacal nitrogen increased to a maximum of 694 p.p.m. in December, 1954, and this order of figure was maintained until October, 1955, when it declined to 447 p.p.m. After this there was a gradual loss until at the conclusion of the experiment in February, 1957, the percolate contained 42 p.p.m.

Nitrite was not produced during the experiment and nitrate, though present initially, was soon lost and did not reappear. Nitrate in the presence of large concentrations of ammoniacal and albuminoid nitrogen is difficult to determine, and although ammonia was removed by distillation before reduction a positive result indicating nitrate nitrogen of the order of 5 p.p.m. was obtained. This was not confirmed by the nitrometer method, and some work, still proceeding, indicates that reduction methods for the determination of nitrate in presence of large concentrations of albuminoid nitrogen compounds give high results.

Although the greater proportion of the organic nitrogen compounds in the percolate were shown by the albuminoid nitrogen test not to be complex, the conversion to ammonia in the tip was slow and the last stage of purification to nitrite and nitrate did not commence.

The percolate at the end of the experiment may be harmless to underground water judged on its B.O.D. and even the excess of organic matter which is unaffected by biological oxidation may be considered of little moment, nevertheless, it is a matter for serious consideration if an effluent with a large concentration of ammonia, or even if purification were more complete, of nitrate, should be allowed access to underground water.

Sulphate and Sulphide (Table VIII, Figure 3.4)

Both sulphate and sulphide were found in the percolate, the latter being formed by the reduction of sulphate. In November, 1954, the concentration was 1,423 p.p.m. SO_4, but by June, 1955, it had fallen to 2 p.p.m. SO_4. With increased rain in the autumn and winter the concentration in the percolate again increased to a new maximum of 1,826 p.p.m. SO_4 in March, 1956, after which it fell rapidly. In July, 1956, despite the abnormal wet weather the concentration did not increase markedly, but in the following winter there was a further marked increase in the sulphate content of the percolate. Anaerobic conditions were present in the refuse pit and in the percolate and the presence of sulphate-reducing bacteria was confirmed in March, 1956. Sulphide in comparatively small amounts (and varying between 2 and 28 p.p.m.S.) has always been present in the percolate, the highest concentration being obtained in winter. Sulphur was most likely retained in the pit as insoluble sulphides formed from the ferrous and other metallic constituents of the refuse.

Chloride

The monthly mean values for chloride are given in Table VIII and are plotted in Figure 3.4. Chloride determinations were first made on the percolate in February, 1955, when 1,845 p.p.m. (Cl) was present. The trend has subsequently been slowly downward with fluctuations similar to that noted in the values for the free ammonia, in that increased rainfall depressed the concentration of chloride. The concentration of chloride fell less than any other constituent; in June, 1956, the concentration was 1,577 p.p.m. and in February, 1957, there still remained 573 p.p.m.

pH

The monthly mean *p*H values of the percolate are given in Table VIII. The *p*H value of the percolate was originally 7·1. It rose to 7·6 in the two months following tipping, but fell again to 7·1. Since then it varied between 7·3 and 7·9, being on the high side when the volume of percolate was low.

The metallic content of the percolate

The house refuse had been tipped without any recovery of material for salvage and so contained a number of articles of both ferrous and non-ferrous metals. The percolate might, therefore, contain traces of these metals in solution. Nothing, however, was known of the amounts likely to be present.

An analysis of a sample of the percolate taken on 8th February, 1956, showed that the metallic content was as follows:

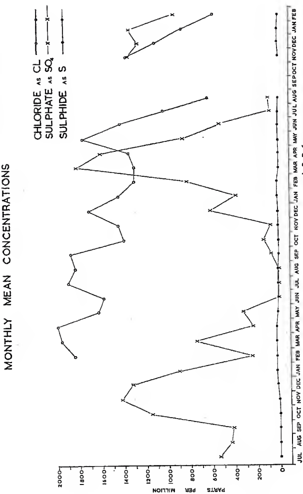
	Unfiltered percolate p.p.m.	Filtered percolate p.p.m.
Iron (Fe)	5·5	3·5
Zinc (Zn)	0·44	0·16
Lead (Pb)	0·1	absent
Copper (Cu).. ..	absent	absent

The metallic content of the percolate was, therefore, insignificant. It is possible that even if some solution of the metal occurred the production of sulphide from the action of sulphate-reducing bacteria on sulphates would have produced sulphides of the metals, which, being insoluble were then retained in the tip.

The chemical character of the percolate toward the end of the experiment

The character of the final percolate is perhaps better judged by its average character over the last few months rather than on data obtained from samples taken at the end of the experiment. For this purpose, it is convenient to consider the last 20 weeks of the experiment which fell in the autumn and winter of 1956. The rainfall during this period was 9·4-ins. which was somewhat greater than the seasonal average. The percolate was 65 per cent of the rainfall, consequently a considerable volume of water had passed through the refuse. The volume of percolate recorded during this period was 21,400 litres or 23 per cent of the total percolate during the whole experiment. The total quantities of polluting matter leached out of the pit during these 20 weeks are given in Table IX below, together with the amount per 1,000 litres of percolate and the average concentration in parts per million. The concentration of polluting matter in a raw domestic sewage is also given for comparison.

FIGURE 3.4.



MONTHLY MEAN CONCENTRATIONS
CHLORIDE AS CL
SULPHATE AS SO4
SULPHIDE AS S
PARTS PER MILLION
0
200
400
600
800
1000
1200
1400
1600
1800
2000
JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB
1 9 5 4
1 9 5 5
1 9 5 6

TABLE IX

THE CHARACTER OF THE FINAL PERCOLATE—PERIOD: LAST 20 WEEKS

122–141 weeks

Percolate	Quantities leached kg	Quantities leached kg/1,000 litres of percolate	Final percolate average conc. p.p.m.	Average domestic sewage p.p.m.
U.O.D. (calculated) ..	—	—	1,002	1,397
B.O.D. (O)	0·91	0·043	43	400
P.V. (O)	2·0	0·093	93	80
Organic carbon (C) ..	4·6	0·215	215	200
Ammonia (N)	1·6	0·075	75	50
Organic nitrogen (N) ..	0·4	0·019	19	22
Chloride (Cl)	14·5	0·678	678	65
Sulphate (SO_4)	20·1	0·940	940	65

The average B.O.D., over the period was 43, individual samples of percolate however varied from 10 to 117 p.p.m. As the average permanganate value and organic carbon were 93 and 215 p.p.m., respectively, it was evident that in spite of a low 5-day B.O.D. value, there was a considerable amount of organic matter not susceptible to biological oxidation in the 5-day test. This was verified by a sample of percolate taken in November, 1956, which gave a 5-day B.O.D. of 16 and a 20-day B.O.D. of 600. A sample of the percolate was therefore sent to the W.P.R.L. and the U.O.D. determined by respirometer. The sample was taken on 3rd December, 1956, and had a 6-day B.O.D. of 17 p.p.m. The U.O.D. (62 days) by respirometer was 900 p.p.m. and that calculated from the formula U.O.D., $= 2 \cdot 67 + 4 \cdot 57$ N was 1,796. A comparison of the concentrations of polluting matter in the percolate and in domestic sewage given in the last two columns of Table IX indicates that the final percolate in spite of a higher content of free ammonia, had a lower biological oxygen demand than an average sewage. The concentrations of chloride and sulphate were, however, considerably greater.

The average daily volume of percolate from the dry tip during this final period was 152 litres. In Table X below is given the quantities in grammes

TABLE X

Character of the Final Percolate—Average Quantities of Polluting Matter per day

Percolate	Percolate average quantity leached per day	Sewage average quantity per capita per day
	g	g
Volume litres	(152)	(135)
B.O.D. (O)	6·5	54
U.O.D. (calculated) (O) ..	153	189
P.V. (O)	14·2	10·9
Organic carbon (C)	32·0	29·5
Organic nitrogen (N)	2·8	3·0
Ammonia (N)	11·5	5·7
Chloride (Cl)	100	9·1
Sulphate (SO_4)	143	9·1

leached daily from the tip during the final period of 20 weeks, together with that in domestic sewage on a per capita basis assuming a flow of 30 galls. per day.

The organic carbon and nitrogen contents of the final percolate were similar to those of crude domestic sewage but the values for ammonia, chloride and sulphate were greater and the B.O.D. less. The experiment confirms the results obtained in the drainpipe experiments (Chapter 2) in that the percolate contained organic matter which was not readily susceptible to biological oxidation.

An analysis of the inorganic content of the percolate is given in Table XI.

TABLE XI

Chemical Analysis of the Percolate obtained from the dry tip on 10th September, 1956

Percolate	p.p.m.
Total dissolved solids at 180°C	4,252
Total dissolved solids at 600°C	3,172
Total hardness as $CaCO_3$	1,376
Calcium hardness as $CaCO_3$	726
Magnesium hardness as $CaCO_3$	650
Alkalinity as $CaCO_3$	2,663
Sulphate as SO_4	72
Chloride as Cl	810
Silicate as SiO_2	60
Sulphide as S	8
Ammonia (free)—N	220
Sodium	600
Potassium	356
Iron (total)	1·5
Copper	absent
Lead	absent
*p*H	(7·9)
Suspended solids	164

C. THE BACTERIOLOGICAL QUALITY OF THE PERCOLATE

A summary of the results of the bacteriological quality of the percolate is given in Table XII and graphed in Figure 3.5. The methods used in the bacteriological examination are given in the Appendix.

Coli-aerogenes group (Table XII)

The colonies grown on MacConkey Agar in roll tubes were under the conditions of the test, assumed to be *coli-aerogenes* and probably at the beginning of the experiment this assumption was reasonably accurate. The slow disappearance of these bacteria with spasmodic increases was unexpected and then a disagreement between the counts of different dilutions of the same sample was observed, the higher dilutions giving lower counts. It appeared that the inhibiting action of the bile salt in the solid medium was insufficient to prevent the growth of other bacteria. In February, 1956, the counts were also estimated by the dilution method using a liquid MacConkey medium and the results being expressed as "The most probable number" (M.P.N.). Comparison between the results given by each method showed that only a fraction of the counts given

by the roll tube method was in fact *coli-aerogenes* and it is evident that the rate of decline of these bacteria was much greater than that shown in Figure 3.5.

E. coli-I (Table XII)

Owing to the limitations of the test for *E. coli-I* referred to in the Appendix the counts of the colonies growing on MacConkey Agar at 44°C. cannot be regarded as a reliable index of the population of *E. coli-I* in the percolate. However, of the colonies picked off the agar for differential tests from July, 1954, to March, 1955, the greater proportion were *E. coli*, and the counts during this period may, therefore, be considered to give an upper limit to the *E. coli* population. These counts are represented by circles in Figure 3.5. The monthly average of the *E. coli* count rose from 1,000 per millilitre in July, 1954, to 600,000 in October, and thereafter declined to 3,000 in March, 1955. After March, 1955, neither the total count of the colonies on the agar roll tube nor the count of the sharp-edged, translucent "coliform-like" colonies can be regarded as having any significance.

Between March, 1955, and February, 1956, the M.P.N. of *E. coli-I* has been calculated from the results of the examination of 10-ml., 1-ml. and 0·1-ml. samples of percolate taken on five different days within a period of two to three weeks, represented by crosses in Figure 3.5. After February, 1956, the M.P.N. of *E. coli-I* was determined for each sample of percolate by the dilution method, using the MacConkey broth containing 0·15 per cent. of bile salt. These results are shown by black dots in Figure 3.5.

The number of *E. coli* per millilitre of percolate actually present probably lies below the line A–B in Figure 3.5 and near the dotted line in the figure. From April, 1955, or 10 months after the beginning of the experiment to January, 1956, *E. coli-I* varied between 2 and 0·1 per millilitre. After February, 1956, it was often absent and never again present to any extent.

Streptococci faecalis (Table XII)

The numbers of *streptococci faecalis* increased from 200 per millilitre in the month after tipping to 10,000 per millilitre in November, 1954. After this, there was a rapid decline to 40 per millilitre in February, 1955.

Between February and August, 1955, the figures are not reliable as other organisms which were present interfered with the test. From September, 1955, the dilution method using liquid media was adopted and the M.P.N. obtained was of the order of 1 per millilitre except for a short period in July, 1956, when higher numbers were present.

TOTAL POLLUTING MATTER LEACHED FROM THE REFUSE AND THAT REMAINING IN THE TIP

Polluting matter leached from the refuse

The total weight of polluting matter leached from the refuse has been calculated from the recorded volumes of percolate and the concentration figures found on analysis. This is given in Table XIII and is arranged in 10-week periods apart from the first which is a 20-week period because of the initial low volumes of percolate. The sum of the quantities leached during these periods gives the total polluting matter from 90 tons of refuse over the whole of the experiment.

The rate of extraction of polluting matter from the refuse in the dry pit has been mentioned earlier in this chapter but a more realistic picture can be given

TABLE XII

Percolate from the dry tip.—Bacteriological data

Month	*Coli-aerogenes* bacteria per ml.		*E. coli-I* per ml.			*Streptococcus faecalis* per ml.	
	Antilog of mean log. Roll tube method	M.P.N. by dilution method	Antilog of mean log. Roll tube method	M.P.N. from 5 successive samples 1 tube of each dilution	M.P.N. 3 tubes of each dilution	Antilog of mean log. (Roll tube)	M.P.N. antilog of mean log
1954 July	50,000	—	1,000	—	—	200	—
August ..	1,000,000	—	200,000	—	—	9,000	—
September ..	1,000,000	—	20,000	—	—	800	—
October ..	7,000,000	—	600,000	—	—	9,000	—
November ..	8,000,000	—	300,000	—	—	10,000	—
December ..	4,000,000	—	60,000	—	—	2,000	—
1955 January ..	3,000,000	—	30,000	—	—	200	—
February ..	800,000	—	10,000	—	—	40	—
March ..	1,000,000	—	3,000	—	—	80	—
April ..	700,000	—	1,000	2·0	—	100	—
				0·4			
May.. ..	400,000	—	300	1·0	—	uncountable	—
June.. ..	100,000	—	70	1·0	—	uncountable	—
				0·08			
July	100,000	—	600	0·10	—	uncountable	—
August ..	500,000	—	6,000	0·4	—	—	—
				0·2			
September ..	400,000	—	7,000	0·1	—	—	1·1
				0·1			
October ..	500,000	—	30,000	0·1	—	—	0·8
			90,000	1·5			
November ..	1,000,000	—	—	—	—	—	0·5
December ..	2,000,000	—	200,000	0·8	—	—	1·6
1956 January ..	700,000	—	200,000	1·0	—	—	0·5
February ..	400,000	430	100,000	—	0·25	—	0·2
		430			0·03		
		93			0		
March ..	300,000	43	—	—	0	—	0·3
		240			0·43		
		430			0·09		
		240			0		
April ..	100,000	240	—	—	0·73	—	1·0
		43			0·03		
		39			0		
		43			0		
May.. ..	100,000	230	—	—	0	—	1·2
		75			0		
		43			0		
		75			0		
		230			0		
June.. ..	50,000	93	—	—	0·03	—	1·1
		930			1·5		
		23			0		
July	300,000	4·3	—	—	0·03	—	4·6
		43			43		110
		4·3			0·93		0·43
		93			43		9
		43			9·3		4
August ..	700,000	7·5	—	—	0·07	—	0·9
		43			15		2
		9·3			1·5		2
November ..	30,000	9·3	—	—	0	—	0
		23			0		0
		93			0·03		0·09
		4·3			0		0·03
December ..	30,000	0·93	—	—	0	—	0·09
		1·5			0		0
		24			0		0
1957 January ..	100,000	23	—	—	0	—	0
		43			0		0
		43			0		0
		4·3			0·03		0
February ..	100,000	2·3	—	—	0	—	0
		110			0		0
		93			0		0
		93			0		0

TABLE XIII

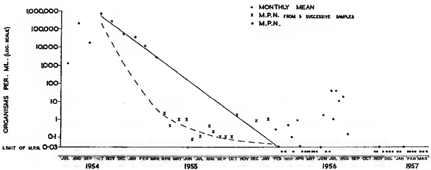
Quantities of Polluting substances leached from refuse

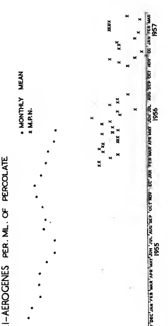
Period 19 June, 1954, to 23 February, 1957		Kilogrammes							
Weeks from start—inclusive		Percolate 1,000 litres	B.O.D.	Permanganate value O (4 hrs.)	Organic carbon	Organic nitrogen	Ammoniacal nitrogen	Chloride as Cl	Sulphate and sulphide as SO_4
1–21	19 June to 13 November, 1954	1·0	2·3	0·4	1·5	0·1	0·4	—	1·1
22–31	13 November to 22 January, 1955	13·3	94·5	11·4	57·2	2·2	8·1	—	18·1
32–41	22 January to 2 April, 1955	8·4	46·6	5·1	27·2	0·9	5·1	—	7·0
42–51	2 April to 11 June, 1955	5·1	23·8	2·3	10·0	0·4	2·6	7·9	1·6
52–61	11 June to 20 August, 1955	1·9	6·0	0·8	4·0	0·2	1·1	3·3	0·1
62–71	20 August to 29 October, 1955	4·7	0·9	0·7	1·7	0·2	1·1	3·5	1·0
72–81	29 October to 7 January, 1956	8·5	12·0	2·6	8·9	0·5	3·4	12·7	2·5
82–91	7 January to 17 March, 1956	15·0	16·2	3·3	13·7	0·6	4·5	19·3	8·9
92–101	17 March to 26 May, 1956	1·9	0·1	0·4	0·8	0·1	0·6	2·7	2·9
102–111	26 May to 4 August, 1956	2·6	0·1	0·5	1·0	0·1	0·6	3·2	0·7
112–121	4 August to 13 October, 1956	10·6	0·2	1·1	2·3	0·2	1·4	6·8	4·6
122–131	13 October to 22 October, 1956	2·3	0·03	0·3	0·6	0·1	0·4	2·3	2·1
132–141	22 October to 23 February, 1957	19·1	0·88	1·7	4·0	0·3	1·2	12·2	18·0
1–141		93·4	203·6	30·6	132·9	5·9	30·5	73·9 103·9*	68·6

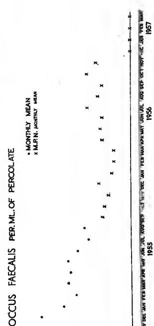
* " Corrected for the estimated amount of chloride in the refuse prior to the regular determination of chloride."

FIGURE 3.5

ESCHERICHIA COLI PER. ML. OF PERCOLATE




COLI-AEROGENES PER. ML. OF PERCOLATE
• MONTHLY MEAN
x M.P.N.
ORGANISMS PER. ML. (LOG. SCALE)
10,000,000
1,000,000
100,000
10000
1000
100
10
1
1954
1955
1956
1957


STREPTOCOCCUS FAECALIS PER. ML. OF PERCOLATE
• MONTHLY MEAN
x M.P.N. MONTHLY MEAN
ORGANISMS PER. ML. (LOG. SCALE)
10000
1000
100
10
1
0·1
LIMIT OF M.P.N. 0·03
1954
1955
1956
1957

on a quantity basis. Four periods have been selected after consideration of the levels of the monthly average concentration of organic carbon, B.O.D. and P.V. given in Table VIII. Table XIV gives the quantity of polluting matter extracted in each period expressed as a percentage of the total amount extracted.

TABLE XIV

Period from start	Weeks in period	Percentage of polluting matter extracted				
		B.O.D.	Organic carbon	P.V. (4 hours)	Amm. N	Organic N
1–61	61	85·1	75·0	65·3	56·7	64·3
62–91	30	14·3	18·3	21·6	29·5	22·1
92–121	30	0·2	3·1	6·5	8·5	6·8
122–141	20	0·4	3·5	6·5	5·3	6·8

The greater part of the B.O.D. and organic carbon were removed from the tip in 61 weeks, the corresponding time in the drainpipe experiments (Chapter 2) being about 52 weeks.

Organic nitrogen and ammonia were extracted more slowly but between 61 and 91 weeks the main bulk of carbon and nitrogen compounds in the total percolate had been extracted.

Character of the refuse remaining in the tip

From the composition of the final effluent it would appear that most of the readily extractable matter had been leached from the refuse and the results given in Table XIV suggest too that further pollution from the refuse in the tip would be small at any one period. Nevertheless there could remain in the tip further sources of polluting matter which might be extracted over a long period of time and give a percolate with a small but persistent load of pollution.

At the end of the experiment the soil and refuse in the tip was excavated. The top layer of refuse was removed from a trench 6 ft. × 1 ft. × 7-ins. across the centre of the tip with as little separation as possible and a weighed sample of 200-lbs. taken for examination. The refuse was comparatively dry, the paper and board being damp without being sodden. The decomposition of the paper had been slight and printed matter was quite legible. No vegetable matter was identified apart from a little twiggy material. The refuse possessed a pronounced cheesy smell. Refuse was next removed, without sampling, until a level 50-ins. from the surface was reached. A 200-lb. sample was then taken at this level by excavating a trench 4 ft. × 1 ft. × 1 ft., care being taken to avoid separation during its removal.

This sample was considerably wetter than the first and the finer material was both more broken down and darker than in the first layer. A blackish deposit was found on some pieces of material. The cheesy odour persisted and to it was added an occasional odour of hydrogen sulphide. Excavation was continued and the clinker bed reached at a depth of 70-ins. from the surface and the bricked bottom of the pit at 78-ins. The clinker was wet and covered with a black slime. Samples of large and small clinker were taken for examination. Mixed with the clinker layer was a fine black sludge and a sample of this was also removed for examination. The proportion of black sludge to clinker was not determined but on inspection was less than 5 per cent by volume.

The 200-lb. samples of refuse were spread out on a tarpaulin and all material large enough was hand-picked and sorted into different lots and each lot weighed. The residue consisted of fine material containing small bits of paper, rags and twigs of a size not larger than 2-ins. The weight of the residue was obtained by difference.

The composition of the refuse from the two layers is given in Table XV.

TABLE XV

Composition of extracted Refuse

Refuse	Top layer lbs.	Bottom layer lbs.
Paper ..	27	36
Rags ..	20	13
Metal ..	22	16
Glass and china	2	14
Bones	5	2
Hedge clippings (twigs)	2	3
Stones	9	5
Residual fine material	113	111
TOTAL ..	200	200

It will be noted that over 50 per cent of the excavated refuse consisted of unidentifiable fine material which in the absence of vegetable and other food debris must have contained their degradation products. An analysis of this material is given in Table XVI.

TABLE XVI

SAMPLES OF MATERIAL FROM THREE LEVELS OF DRY TIP

Chemical Analysis of material remaining after abstraction of coarser substances, i.e., the "fine residue"

Sample as received	Top layer	Bottom layer	Clinker layer
Loss on air drying (per cent)	27·6	43·8	49·2
Sulphide as S p.p.m.	124	1,016	3,272
Volatile acid as acetic p.p.m.	1,370	2,700	2,400
Sulphate-reducing bacteria	+	+	+
On air-dried sample (ground to pass B.S. sieve No. 60)		per cent	
Moisture at 105°C	3·91	4·45	4·14
Loss on ignition	20·28	41·04	42·40
Silica as SiO_2	67·06	46·24	43·12
Calcium as CaO	1·57	2·56	3·02
Magnesium as MgO	0·98	0·95	0·60
Iron and aluminium as R_2O_3	8·91	7·08	8·10
Sulphate as SO_4	0·18	0·49	0·89
Phosphate as P_2O_5	0·41	0·50	0·30
Chloride	trace	trace	trace
Zinc ..	absent	absent	absent
Lead ..	absent	absent	absent
Copper	0·02	0·08	0·03
Organic Nitrogen	0·40	0·70	0·56
Organic carbon	6·75	23·8	25·1

It is clear that the pollution as represented by organic carbon has moved downwards in the tip and is mainly in the bottom of the refuse and in the clinker. The higher content of silica in the top layer may be due to the penetration of some soil into the refuse.

The chief polluting fractions in the refuse excavated from the pit were the residual fine material and the paper and rags. Water extracts of these were made in the laboratory using ammonia-free water and the extraction continued overnight. The extracts were analysed and the results expressed as milligrammes per kilogramme of material are given in Table XVII.

TABLE XVII

Water extracts of samples from the dry tip expressed as mg./kilogramme of material

Layer	Top layer			Bottom layer			Clinker layer		
	Rags	Paper	Fine residue	Rags	Paper	Fine residue	Small clinker	Large clinker	Fine residue
Free NH_3-N ..	14	16	24	44	46	60	20	12	82
Albd. NH_3-N	83	80	37	84	83	160	5	2	160
P.V. 3 min. ..	158	61	140	173	89	816	14	7	768
4 hrs. ..	430	461	408	493	503	2,320	40	15	1,808
Org. C ..	1,200	1,390	1,400	1,210	1,800	3,400	88	35	3,000
Org. N ..	109	123	76	155	120	320	7	3	350
B.O.D. ..	1,155	1,460	600	1,000	2,060	2,400	66	32	2,000
Sulphide (S) ..	13	9	40	26	14	240	9	0	504
Sulphate (SO_4)	250	565	1,120	1,060	515	4,680	230	570	6,240
Chloride (Cl)..	100	130	80	230	220	400	44	29	1,080
Alkalinity as $CaCO_3$ ..	—	—	1,000	—	—	2,520	—	—	3,320
Ca Hardness as $CaCO_3$ ..	—	—	1,200	—	—	3,520	—	—	5,120
Mg Hardness as $CaCO_3$ ..	—	—	0	—	—	160	—	—	880
T.D.S. 180°C	—	—	3,920	—	—	10,600	—	—	15,040
500°C	—	—	3,280	—	—	10,400	—	—	13,440
Iron (Fe) ..	—	—	52	—	—	120	—	—	80
Zinc	—	—	24	—	—	0	—	—	0
Copper and Lead ..	—	—	0	—	—	0	—	—	0

The fine residue in the clinker layer gave a similar extract with respect to organic matter to that of the residual material in the bottom layer of refuse. This sludge is therefore the finer material washed from the refuse.

The extracts of the residual material from the bottom layer of refuse gave values for the free ammonia, P.V., organic carbon and nitrogen, B.O.D., sulphate and sulphide several times greater than that found for the material in the top layer. The extracts of the paper in the bottom layer were somewhat stronger than that in the top layer. There was little difference in the extracts of the rags.

An estimation can be made of the readily extractable polluting material remaining in the tip on a quantity basis if it can be assumed that the weight of the refuse at the time of excavation was of the same order as when it was tipped. Because of absorption of water by the relatively dry refuse, leaching by rain and losses to the air following fermentation the residual weight cannot be accurately assessed and any calculation can only give an approximation of residual polluting material.

An estimate of the quantities of organic matter and chloride of the refuse left in the tip can be taken to be an average of that found in the top and bottom layers and is given in Table XVIII.

TABLE XVIII

Quantities of water extractable polluting material left in the dry tip

	kg.
B.O.D.	110
Organic carbon	155
P.V. (4 hours)	80
Organic nitrogen	13
Chloride Cl	16
Ammonia N	3

It is emphasised that the figures representing polluting matter in refuse can be only very approximate. No allowance has been made for differences in moisture content. Nevertheless it is of interest to compare the water extractable chloride and P.V. contents of the fresh refuse, the total percolate and the spent refuse. These are given in Table XIX.

TABLE XIX

kilogrammes

	In fresh refuse (1)	In the total percolate (2)	In spent refuse (3)	1−(2+3)
Chloride (Cl) ..	88	104	16	−32
P.V. (4 hours) ..	172	31	79	62

In comparison with chloride there was an appreciable loss of P.V. and this indicates that fermentation changes within the refuse itself resulted in degradation products which were to a large extent lost to the atmosphere and which did not appear in the percolate.

The refuse at the end of the experiment still contained polluting material and the presence of H_2S particularly in the bottom layers showed that it was still in a septic condition after 33 months. To get some idea how long this condition would be likely to persist some old tips in the Twickenham area were opened and the condition of the refuse examined. The results of visual inspections are given in Table XX.

TABLE XX

Visual Inspection of old tips

Age of tip. Years	Remarks
2	Not broken down, putrid smell, typical refuse paper, etc.
3	Some breakdown, black appearance, not much paper. Definite smell. Wire mesh not corroded.
4	Dry earthy appearance, fair amount of paper, some print legible but mostly disintegrated. Almost no smell.
5	Nearly all black, very slight smell, fair amount of paper, print legible.
10	Completely broken down. Iron oxidised, aerobic condition. No paper and no smell.

Samples were taken of the refuse and water extracts prepared. The results of the analyses of these extracts are given in Table XXI.

TABLE XXI

Chemical examination of samples taken from old tips

Age (years)	Parts per million				
	2	3	4	5	10
B.O.D.	75	16	16	14	3
P.V. (4 hours)	13·1	14·5	13·5	13·2	5
Organic carbon	52	27	16	11	—
Organic nitrogen ..	1·8	1·7	1·2	1·7	0·8
Ammoniacal nitrogen ..	4·0	4·7	2·7	4·3	0·4

After 10 years nothing in the way of potential pollution remained and even after four years the remaining polluting material was negligible.

Further experiments on the percolation of rain water through refuse in drainpipes

Good agreement was obtained between the results given by the drainpipe experiments (Chapter 2) and those described in this chapter. It was decided therefore to begin two more drainpipe experiments while the pilot scale plants were still running and facilities were available at the site.

The first was designed to show the effect of filtering the percolate through 3 ft. of 1½-in. ballast of which particulars are given in Chapter 5. The second experiment was planned to see how a winter refuse tipped in early winter would respond to rainfall with respect both to percolation and to the rate of self purification.

The effect of filtration

Two 3-ft. lengths of drainpipe were filled with refuse, from the same collection, on the 23rd June, 1955. Pipe A was mounted direct onto a base to collect the percolate. Pipe B was joined to another 3-ft. length of drainpipe which was filled with 1½-in. ballast, the join between the two pipes being cemented and the whole was mounted on a base to collect the filtered percolate.

The amount of percolate obtained was not always sufficient for analysis and there were quite long periods when practically no percolate was produced. The results are not given in detail but Table XXII gives the relevant chemical information.

TABLE XXII

Comparison of percolate from Pipes A and B

Date tipped 23rd June, 1955		A No ballast	B With ballast
First percolate ..	after	119 days	120 days
	after	19 litres rain	19 litres rain
Strength ..	.. P.V. (4 hours)	394 p.p.m.	72 p.p.m.
	B.O.D.	300 p.p.m.	100 p.p.m.
	Org. C	735 p.p.m.	210 p.p.m.
	Org. N	90 p.p.m.	—*
	NH_3–N	116 p.p.m.	—*
	(NO_2+NO_3)–N	133 p.p.m.	—*
Purification to B.O.D. of about 20 p.p.m. or better	after	201 days	138 days
	after	37 litres rain	26 litres rain
	after	11 litres percolate	1·6 litres percolate
	P.V. (4 hours)	175 p.p.m.	25 p.p.m.
	B.O.D.	22 p.p.m.	5 p.p.m.
	Org. C	360 p.p.m.	43 p.p.m.
	Org. N	17 p.p.m.	13 p.p.m.
	NH_3–N	11 p.p.m.	<0·5 p.p.m.
	(NO_2+NO_3)–N	50 p.p.m.	—*
Percolate ..	.. after	220 days	201 days
	after	43 litres rain	37 litres rain
	after	17 litres percolate	6 litres percolate
	P.V. (4 hours)	144 p.p.m.	57 p.p.m.
	B.O.D.	6 p.p.m.	8 p.p.m.
	Org. C	278 p.p.m.	250 p.p.m.
	Org. N	16 p.p.m.	15 p.p.m.
	NH_3–N	3 p.p.m.	2 p.p.m.
	(NO_2+NO_3)–N	50 p.p.m.	50 p.p.m.
Final percolate	.. after	395 days	395 days
	after	68 litres rain	68 litres rain
	after	32 litres percolate	22 litres percolate
	P.V. (4 hours)	53 p.p.m.	38 p.p.m.
	B.O.D.	4 p.p.m.	8 p.p.m.
	Org. C	88 p.p.m.	86 p.p.m.
	Org. N	8 p.p.m.	5 p.p.m.
	NH_3–N	0·9 p.p.m.	3 p.p.m.
	†(NO_2+NO_3)–N	166 p.p.m.	264 p.p.m.

Notes:

* Insufficient percolate for complete analysis.

† Nitrate in both pipes increased after this and later decreased.

Air had access to the drainpipes and nitrification was well advanced before the end of the experiment.

In Pipe A about 200 days were required for the B.O.D. of the percolate to approach the standard recommended by the Royal Commission on the disposal of sewage but 395 days were required before a marked lowering of the organic carbon occurred. About this time too nitrification was proceeding rapidly. Pipe B although it contained a comparable potential pollution never produced as strong an effluent as did Pipe A, and the effectiveness of the filtration through ballast was marked. In 138 days from tipping the effluent was of good quality, not only as regards B.O.D. but also P.V. and organic carbon which, having regard to the figures obtained for both pipes after nearly 400 days, appeared to have reached an irreducible minimum. It will be noted that nitrification was active in both pipes after about 395 days although in Pipe B purification up to this stage had occurred much earlier. This may be a temperature effect as nitrification actually took place in July.

The bacteriological results are summarised in Table XXIII.

TABLE XXIII

Comparison of Pipes A and B—Bacteriological Data

Date tipped 23 June, 1955	Most probable number per ml.					
	Coli-aerogenes group		*E. coli-I*		Faecal *streptococci*	
	A	B	A	B	A	B
1st percolate:						
after 119 days ..	240,000	43,000	15,000	750	11,000	23
after 120 days ..	930,000	43	15,000	4	2,400	0
after 123 days ..	24,000	24	750	0·4	930	0
after 125 days ..	24,000	<1	240	0	75	0
after 250 days ..	9,300	<1	93	0	430	0
after 355 days ..	0	0	0	0	0	0

Coliform bacteria persisted, in diminishing number, in Pipe A for 250 days, as did faecal *streptococci*. In Pipe B high counts were obtained only in the first percolate of 0·42 litres and the numbers were much less than those in the first percolate from Pipe A. After this in Pipe B bacteria rapidly disappeared and in four days were for all practical purposes absent.

Discussion.—The effect of filtering the percolate through as little as 3-ft. of gravel was such as to suggest that bacterial pollution of an underground water from the percolate of rain water through refuse could be prevented.

Chemical pollution by organic matter could also be markedly reduced and its duration drastically curtailed. There appeared to be a lower level of organic carbon content beyond which little change occurred and nitrification took place late in both pipes. The concentration of nitrate eventually reached was the most serious aspect of the effluent, the highest figure reached in Pipe B being nearly 900 p.p.m. as nitrogen. The chloride was unaffected by filtration and the highest concentration reached in either pipe was about 2,600 p.p.m. as chlorine, the lowest concentration at the end of the experiment being about 100 p.p.m. as Cl.

Winter Refuse tipped in October

A 3-ft. length of drainpipe was filled with refuse on 5th October, 1955, and exposed to rainfall.

An excerpt of the results obtained is given in Table XXIV.

TABLE XXIV

Chemical quality of the Percolate from Pipe C

Date tipped 5th October, 1955

First percolate	after	84 days
	after	13 litres rain
	P.V. (4 hours)	173 p.p.m.
	B.O.D.	775 p.p.m.
	Org. C.	840 p.p.m.
	Org. N.	73 p.p.m.
	NH_3–N	217 p.p.m.
	(NO_2+NO_3)–N	7 p.p.m.
Percolate	after	97 days
	after	23 litres rain
	after	7·6 litres percolate
	P.V. (4 hours)	45 p.p.m.
	B.O.D.	45 p.p.m.
	Org. C.	124 p.p.m.
	Org. N.	13 p.p.m.
	NH_3–N	245 p.p.m.
	(NO_2+NO_3)–N	5 p.p.m.
Percolate	after	274 days
	after	48 litres rain
	after	20 litres percolate
	P.V.	24 p.p.m.
	B.O.D.	4 p.p.m.
	Org. C.	51 p.p.m.
	Org. N.	4·7 p.p.m.
	NH_3–N	0·8 p.p.m.
	(NO_2+NO_3)–N	167 p.p.m.

The figures given in this table should be compared with those given for Pipe A in Table XXII. A percolate was obtained from Pipe C in a shorter time and with less rainfall than in Pipe A because of a lower rate of evaporation in the winter months. The strength of this percolate judged by the P.V. was less than that given by Pipe A but judged by the B.O.D. it was greater mainly because of a higher concentration of ammonia. Nevertheless, after 97 days or 13 days from the appearance of the first percolate its strength disregarding ammonia was similar to that given by the percolate from Pipe A after 201 days or 82 days from the beginning of percolation. In these periods Pipe A produced 11 litres of percolate and Pipe C 7·6 litres percolate. The Spring of 1956 was dry and insufficient percolate was produced from any of the drainpipes for analysis but an analysis in July, 1956, after 274 days from tipping showed that the strength of the effluent from Pipe C was of good quality and similar to that from Pipe A at the same time.

The bacteriological results are summarised in Table XXV.

TABLE XXV

Bacteriological quality of the Percolate from Pipe C

Date tipped 5th October, 1955	*Coli-aerogenes* group	M.P.N. per ml.	
		E. coli–I	Faecal *streptococci*
1st percolate:			
after 65 days ..	9,300	93	4
after 69 days ..	43,000	240	<1
after 78 days ..	9,300	150	2
after 176 days ..	2,300	2	27
after 183 days ..	230	4	15
after 246 days ..	9	0	0
after 267 days ..	0	0	0

Bacteria persisted throughout the winter months and it was not until June, after 246 days from tipping, that those of faecal origin disappeared. In July all types of coliform bacteria and faecal *streptococci* were absent.

4. Disposal of House Refuse in Wet Pits—Laboratory Scale Experiments

The objectives of the laboratory tank experiments were to determine the degree of pollution imparted to a potable water on passing through house refuse and how this varied with time and also to determine the permeability of the refuse. In the first tank experiment the water after passing through the refuse was mixed, chiefly for sampling purposes, and then again recirculated through the refuse. Except for that abstracted for analysis the volume of water in the tank was constant and there was no dissolved oxygen in the circulating liquor. In the second tank experiment the refuse was continuously percolated with fresh tap water which after passing through the refuse was mixed by a pump and allowed to overflow to waste. In this case the percolating water was of potable quality and contained dissolved oxygen. In the first experiment 44 samples were examined chemically and 72 bacteriologically. The corresponding numbers in the second experiment were 46 and 36.

THE FIRST TANK EXPERIMENT

The Character of the Refuse

The refuse consisted of refuse screenings from house refuse collected in March and was supplied by the Tottenham Borough Council. It was supplied in six bags and each bag was separately analysed. The following data gives the average values found for this refuse.

(*a*) Bulk Density .. .. As filled .. 34·5-lbs. per cubic foot.
After tapping 47·1-lbs. per cubic foot.

(b) Sieve analysis, description and ash content of Sieve Fractions:

B.S. sieve number	Percentage retained	Ash per cent	Description
7	42	58·8	Mainly coke, glass, paper
18	17	59·7	Mainly coke, fibre, grit
30	8	69·2	Mainly coke, fibre, grit
60	9	73·3	Coke. Some dust
100	5	71·0	Dust
passing 100	18	78·7	Fine dust

(c) Chemical analysis:

	Per cent
Moisture at 105°C.	10·7
Ash	54·4
Sulphate:	
Total (SO_4)	2·59
Water soluble (SO_4)	1·68
Sulphide:	
Total (S)	0·06
Water soluble (S)	0·03
Chloride: Water soluble (Cl) ..	0·19
Nitrogen: Total organic (N) ..	0·75*
Carbon: Total organic (C)	18·10*

* On refuse after storage for three months.

*p*H of aqueous extract 20g/litre ..	7·6–8·2
Conductivity of aqueous extract 20g/litre	950–1,000 mhos/cm. cube

Experimental Procedure

A 400-gall. rectangular iron tank was fitted with two partitions of steel netting placed 18-ins. apart and the space between was filled with 7⅞ cub. ft. of refuse screenings. The tank was filled with M.W.B. tap water, 146 gallons being necessary to raise the level of the water to within 1-in. of the top of the refuse. The water was forced through the refuse by the hydraulic head of water obtained by pumping the water from one side of the refuse and delivering it to the other side, the rate of pumping being adjusted so that the head of water did not flood over the top of the refuse. Initially, a 1-in. head of water was maintained at a pumping rate of 13 gallons per hour. Four weeks later, the head required was 2-ins. at a pumping rate of 12-galls. per hour and at seven weeks with a head of just over 3-ins. the pumping rate had to be reduced to 3-galls. per hour to prevent flooding of the surface of the refuse.

From these figures and the dimensions of the refuse compartment the permeability of the refuse was calculated by the Darcy formula (see Chapter 5) and found to diminish from 7·74 during the initial stages of the experiment to 0·59 during the latter half of the experiment.

The liquor on the effluent side of the refuse was mixed by a pump and samples taken for chemical and bacteriological examination on alternate days. The temperature in the interior of the refuse was recorded and found to be the same as that of the circulating liquor. It slowly increased from 10°C. at the start of the experiment on the 20th March, 1953, to 16·5C. at its conclusion on the 22nd June, 1953.

The appearance of the Liquor

The liquor during the first half of the experiment was greenish-grey and possessed a stale odour which occasionally was fishy or acetylenic in character. Within a week of commencing the experiment a brown scum was formed on the surface of the effluent liquor. This was examined and found to consist essentially of a mucor together with numerous protozoa. No iron bacteria were detected. After the 11th May, 1953, the liquor considerably darkened and smelt predominantly of hydrogen sulphide. The scum floating on the liquor on the effluent side of the refuse was blackish-brown near the refuse and white further away. The mineral matter in the brown scum was chiefly calcium carbonate with a considerable amount of iron oxide together with 1·5 per cent of elementary sulphur. The white scum consisted mainly of calcium carbonate with 14·6 per cent of elementary sulphur. No mould was observed in either the brown or white scum.

Chemical Results

From the start of the experiment until its conclusion, dissolved oxygen was never present in more than traces and after the 40th day was completely absent. The Biochemical Oxygen Demand rose to 360 p.p.m. by the 12th day, fell rapidly to 36 p.p.m. on the 55th day and from then rose slowly to 128 p.p.m. on the 87th day. The trend in the organic carbon was similar, with an increase to 212 p.p.m. on the 21st day followed by a decline to 48 p.p.m. on the 61st day and then a slow rise to 78 p.p.m. on the 92nd day. Within a few days the organic nitrogen rose to 17·5 p.p.m. and the albuminoid nitrogen to 13 p.p.m., after which, both fell slowly and somewhat irregularly until on the last day the concentrations were 4·2 and 3·2 p.p.m., respectively. Nitrites were only occasionally detected and then in traces. The free ammonia content which was initially 9 p.p.m. (N) rose steadily and almost continuously throughout the experiment until at the end there was 29 p.p.m. (N) ammonia nitrogen in the liquor. The sulphate content of the liquor rose rapidly to a maximum of 2,128 p.p.m. (SO_4) on the 12th day, followed by a steady decline to 670 p.p.m. on the 92nd day.

The sulphide content of the liquor was initially 4 p.p.m. and this rose slowly at first but more rapidly in the later stages until it attained a final concentration of 49·6 p.p.m. (S).

Summary of Chemical Examination of Tank Liquor

	Concentration p.p.m.			
	Initial	Maximum	Minimum	Final
Biochemical oxygen demand (five days) ..	98	360 .	36	128
Organic carbon	54	212	48 ·	78
Organic nitrogen	8	17·5	—	4
Ammoniacal nitrogen	9	33	—	29
Albuminoid ammonia	8	13	—	3
Sulphate, as SO_4	677	2,128	—	670
Sulphide, as S	4	—	—	50

Bacteriological Results

The samples were examined by the roll tube technique described in the Appendix of this report. After reaching a maximum shortly after the experiment

commenced, the numbers of organisms in the liquor decreased fairly continuously during the course of the experiment. The table below shows the decrease in population.

Summary of Bacteriological Counts on the Tank Liquor

	Organisms per millilitre (thousands)		
	Maximum	Final	After final wash
Total viable count (Nutrient agar, two days at 30°C.)	124,000	800	135
Coliform-aerogenes group (MacConkey agar, one day at 37°C.)	1,520	29	0·6
E. coli-I (MacConkey agar, one day at 44°C.)	223	0·07	0·002

At the conclusion of the experiment on the 92nd day the water from the effluent side was pumped to waste at the rate of 2-galls. per hour and tap water was supplied at the same rate to the inlet side of the refuse compartment. This was continued for 12 days during which period 576-galls. of potable water had entered the tank. The bacterial populations in the effluent liquor fell considerably and are given in the last column of the above table.

THE SECOND TANK EXPERIMENT

The Character of the Refuse

The refuse was supplied by Watford Borough Council and represented average house refuse without the addition of industrial wastes and it had not received either hand or mechanical separation. The following analysis giving the percentage composition of the refuse by categories was supplied with the refuse.

Composition of the refuse

	Per cent by weight
Fine cinders, ⅜-in.	16·6
Small cinder, ⅜-in. to ¾-in.	10·2
Large cinder, ¾-in. to 1½-ins.	9·5
Vegetable and putrescible content	26·0
Paper	18·1
Metal:	
Food containers	3·3
Other containers	0·5
Other metal	3·2
Rag	1·8
Glass	5·8
Bones	0·8
Combustible debris	2·8
Incombustible debris	1·3
	99·9

Experimental procedure

The refuse compartment of the 400-gall. tank was filled with 5·3 cub. ft. of refuse. M.W.B. mains-water was added continuously at one end of the tank and after passing through the refuse was mixed by a water-pump and then allowed to overflow to waste through a constant level tube.

At the beginning of the experiment the flow of water into the tank was at the rate of one litre an hour but after 10 days this was increased to two litres per hour in order to reduce the strength of the effluent to a value similar to that found in the lagoons at the Egham gravel pits where the large-scale tipping of house refuse was then in operation. Measurements of the volume of water needed to fill the tank when empty and when the steel partition was filled with refuse showed that the refuse absorbed about one-third of its volume of water. The initial volume of water in the tank was 150-galls. At the conclusion of the experiment, which continued for 190 days, 1,840-galls. of fresh water had passed through the refuse.

Flow rates and permeability

The passage of two litres per hour of water through the refuse compartment of 3·94 sq. ft. cross section corresponds to a rate of flow of 0·018 cub. ft. per square foot per hour which was a considerably slower rate of flow than in the first tank experiment.

The permeability (K) of the refuse calculated by Darcy's Law for laminar flow, from the dimensions of the refuse compartment, the rate of flow of two litres or 0·0706 cub. ft. per hour, and the observed head of 0·1-in., was 3·22. This was similar to that of the refuse screenings in the first tank experiment when the hydraulic head was 2-ins. Samples were withdrawn from the tank every other working day for chemical and bacteriological examination.

The appearance of the liquor

The initial effluent from the refuse was opalescent, slightly yellow and smelt of rotting vegetables. Within a few days a white mould covered the surface and after a fortnight the liquor became black and turbid and smelt of hydrogen sulphide. The mould next became brownish and slimy after which the greater part sank to the bottom of the tank. The smell of hydrogen sulphide disappeared after six weeks and was replaced by a vegetable or stale odour and the colour became lighter. The surface again became covered with a brownish-white mould which consisted of a mucor and contained some fusaria. The scum was examined but unlike that in the first experiment it contained no free sulphur.

Chemical characteristics of the tank liquor

Dissolved oxygen was absent in the first sample of liquor examined and remained absent until near the end of the experiment. The initial effluent from the refuse was highly polluting and in nine days the Biochemical Oxygen Demand had reached its maximum value of 1,200 p.p.m.

Under these anaerobic conditions sulphide was produced almost immediately and rose to a maximum of 23 p.p.m. in 20 days. The Biochemical Oxygen Demand dropped fairly rapidly to 52 p.p.m. in 90 days, then fell slowly to 15 p.p.m. on the 132nd day from the start of the experiment. The permanganate value (in this case the difference between the 4 hours and 3 minute readings) and

the organic carbon behaved similarly. The free ammonia increased to 41 p.p.m. in nine days and then fell to just over 1 p.p.m. at the conclusion of the experiment. Organic nitrogen was reduced from its maximum value of 25 p.p.m. in 12 days to 1·5 p.p.m. in 90 days.

The sulphate content very rapidly increased to 206 p.p.m. in nine days but this rapidly fell to 2 p.p.m. in 30 days. Sulphide rapidly increased and in three weeks attained a maximum value of 23 p.p.m. after which it fell to seven parts in six weeks and remained at this level until near the end of the experiment. After 160 days the strength of the effluent was similar to that of a good sewage works effluent and at this stage sulphide had dissappeared and dissolved oxygen was present. In addition the onset of nitrification was indicated by the appearance of nitrate.

The chemical data are briefly summarised below and are given in full in Figures 1 and 2.

Summary of chemical data on liquor in second tank experiment

	Concentration p.p.m.					
	14 Aug. 1953	21 Aug. 1953	2 Sept. 1953	19 Oct. 1953	22 Dec. 1953	4 Feb. 1954
Days from start ..	2	9	21	68	132	176
Biochemical oxygen demand	640	1,200	900	235	15	3·6
Organic carbon ..	308	560	475	92	14	8
Permanganate value (4 hrs.—3 mins.)..	134	126	94	13	6	1·5
Ammoniacal, NH_3	22	41	37	10	2·0	1·3
Albuminoid, NH_3 ..	12	14	8	1·3	0·9	0·5
Oxidised nitrogen ..	0·8	1·2	0·7	0·4	0·1	1·2
Organic nitrogen ..	23	24·5	14	2·1	0·9	0·6
Sulphate, SO_4 ..	161	206	71	2	12	50
Sulphide, S ..	<1	2	23	6·4	6	0·8

Bacteriological data

The initial effluent contained large numbers of bacteria and was grossly polluted. The numbers fell as the experiment continued and the improvement in quality of the effluent is illustrated by the following table:

	Numbers of bacteria per millilitre of effluent		
	Days from start		
	2	6	176
Coliform-aerogenes group ..	32,700,000	20,000	50
E. coli-I	13,000,000	50	<0·1
Faecal *streptococci*	2,480,000	30	<1·0

FIG. 4.1

LABORATORY TANK EXPERIMENTS

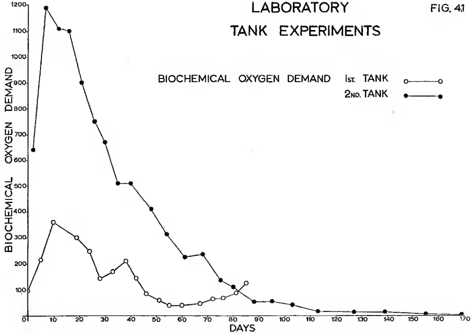
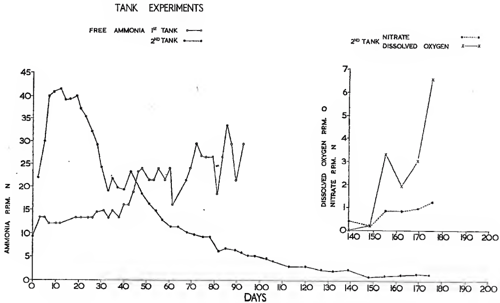


FIGURE 4.2



TANK EXPERIMENTS
FREE AMMONIA 1ST TANK
2ND TANK
2ND TANK NITRATE
DISSOLVED OXYGEN
AMMONIA P.P.M. N
DISSOLVED OXYGEN P.P.M. O
NITRATE P.P.M. N
DAYS

Comparison of the chemical data on the two tank experiments

The refuse in the first experiment consisted of screenings from a winter collection and contained a high proportion of ash, whereas that in the second experiment was unsorted refuse from a summer collection and contained considerably more vegetable matter and less ash. This difference in character is apparent in the analytical data of the tank liquor particularly in the greater initial pollution of the unsorted summer refuse and the large sulphate content of the effluent from the screenings. The main features of the first experiment in which the effluent was continuously circulated through the refuse were:

(1) the considerable reduction in the polluting character of the tank liquor that occurred during the 92 days of the experiment. As measured by the Biochemical Oxygen Demand and organic carbon the self-purification of the tank liquor was 64 per cent and 62 per cent, respectively, of the maximum values attained;

(2) the steady increase in the concentration of free ammonia of the effluent, indicating that the decomposition of the organic nitrogen compounds was a continuous process;

(3) the gradual increase in the C/N ratio from an initial value of 7 to a final value of 18, indicating that the decomposition of the organic nitrogen bodies was proceeding at a relatively faster rate than the decomposition of the carbonaceous matter;

(4) the comparatively slow decrease in the sulphate content of the effluent showed that the sulphate reserve of the screenings was high as sulphate-reducing bacteria were active throughout the experiment;

(5) the formation of elemental sulphur.

In the second tank experiment in which fresh water was passed through the refuse the following summarises the main observations:

(1) The reduction in Biochemical Oxygen Demand in 68 days was 80 per cent of the maximum value reached and in 132 days only 15 p.p.m. of Biochemical Oxygen Demand was present in the tank effluent.

(2) The ammonia rose to a peak and thereafter declined, the final concentration being about 2·0 p.p.m. N. At this stage some nitrate was produced and the effluent was no longer anaerobic. The nitrate produced was not equivalent to the amount of ammonia lost.

(3) The C/N ratio increased from 13 to 46 during 68 days but after this it decreased rapidly to the end of the experiment, indicating a slowing up of the rate of decomposition of nitrogen compared to that of carbon compounds or a stabilisation of the system.

(4) The lower ash content of the unsorted refuse in the second tank experiment gave a maximum concentration of sulphate in the percolate of only 204 p.p.m. compared with a maximum of 2,140 p.p.m. in the tank liquor from the refuse screenings. The lower sulphate reserve in the unsorted refuse and the continuous percolation reduced the sulphate content of the effluent to between 2 and 6 p.p.m. in 30 days. Subsequently, the effluent remained at this figure although the percolating London tap water had a sulphate content varying from 40 to 50 p.p.m. indicating the continuous activity of the sulphate-reducing organisms.

(5) Elemental sulphur was not formed.

General

The refuse gave effluents grossly contaminated with bacteria, that from the unsorted refuse in the second experiment being heavier. The general trend in the fall in numbers of the coliform organisms and of *E. coli–I* as the experiment proceeded was similar in both cases.

Filtration through chalk

Samples of tank liquor from the second tank experiment were filtered through graded chalk. The filter consisted of a 3-ft. pipe, 1 ft. in diameter, filled in layers with graded fragments of chalk of sizes ½-in. to 2-ins. with the coarser material at the bottom. The effluent was added at the rate of 1·5 litres per hour (equivalent to 0·4-galls. per square foot per hour). The strength of the tank liquor available for filtration was not high because the second tank experiment had been started some time previously and the percolated liquor had already become weak. The purification achieved by filtration is shown in the following table:

Composition of tank liquor before and after filtration through chalk

Units—p.p.m.	Experiment I		Experiment II		Experiment III	
	Before	*After*	*Before*	*After*	*Before*	*After*
Free ammonia, N ..	5·2	4·2	6·7	5·6	2·0	1·2
Nitrous and nitric nitrogen	0·3	1·1	0·6	1·1	0·3	2·3
Permanganate value, 4 hrs.	14·4	15·2	25·4	16·5	13·5	6·8
B.O.D. (five days)	36	14	31	14	15	7

The tank liquors were therefore amenable to purification in a vertical filter in which conditions were aerobic.

5. Design of the Pilot-Scale Plant Experiment on the Disposal of House Refuse in Wet Pits

Preliminary experiments on the percolation of water through refuse, described in Chapter 4, showed that a heavily-polluted effluent was produced. This effluent, judged on its B.O.D. was, at its worst, about three times as strong as raw domestic sewage, and was in fact comparable with that produced under natural conditions at Egham (1) (2). Direct access of such an effluent to a water table, particularly when water is abstracted for domestic use, could not be contemplated, and if this were the whole story further experimental work would not have been justified. In practice, however, an effluent from a wet pit could be expected to undergo some purification as it passed through the ground and since this, in the vicinity of worked-out gravel pits, would be similar in a sense to gravel or sand, the ultimate effect might approach that obtained by normal filtration processes.

The absence of dissolved oxygen, demonstrated by the production of H_2S in a natural wet pit would give conditions different in character from those in a normal biological filter where the system is aerobic and little was known as to the degree and nature of purification that would be obtained in such an anaerobic system; eventually of course dissolved oxygen in the ground water would begin to play its part.

It was decided, therefore, that the effluent from the wet pit in the pilot-scale plant should be passed through different lengths of filtering material of known size. Examinations of the effluent before and after filtration should then give a measure of the purification effected by a definite length of a known grade of material.

Further, the amount of self-purification within the tip itself, such as occurred in the dry tip experiments described in Chapters 2 and 3, required to be assessed under the conditions arising where the refuse was partially submerged in water, and it was also important to know something about the permeability of the refuse and if water would readily pass through rather than around the perimeter of the refuse tip.

It was considered that tipping into the wet tip should be intermittent and that the strength of the liquor in the tip should be similar to that occurring naturally, e.g., at Egham.

The flow of underground water depends on the nature of the soil and the hydraulic head, and Slichter (3) gives rates of flow under a head of 10 ft. per mile of 0·6 ft. per day for medium sand and 2·3 ft. for coarse sand. An average flow of underground water was understood to be of the order of 1 ft. in 24 hours, and flows through the experimental plant were arranged as near as possible to this estimate.

It was planned to have 12 horizontal filters, three series of four different lengths from 6 to 24 feet, each series being filled with a different grade of filtering material.

The size of the filters was such that a flow of about 1 ft. per day corresponded to a volume of about 5 litres per hour through each filter.

In addition to filtration through the 12 horizontal filters, it was desired to pass the effluent from the wet tip through three vertical filters, 6 ft. × 1 ft. diameter, each filled with one of the grades of filtering material used in the horizontal filters. These vertical filters would act as biological filters with a free access of air, and thus give a direct comparison between the two forms of filtration.

Permeability of the refuse

In Darcy's Law for laminar flow there is a critical velocity above which the flow becomes turbulent, and therefore outside the scope of the law. Chebotarew (4) gives this critical velocity for coarse sand to be 0·5 cm. per second, or approximately 1,300 ft. per day. This velocity is so much greater than that planned for the pilot-scale experiment that laminar flow was assumed.

Darcy's Law states that if Q is the quantity of water passing a cross-section of area F of a bed of material under an hydraulic gradient I, then

$$Q \propto F.I.$$

The constant ratio $\frac{Q}{F.I.}$ is designated by K and is called the coefficient of permeability. So that

$$Q = K.F.I.$$

As I is a fraction without dimensions, where Q is measured in cubic feet per hour and F is square feet, K will be a velocity in feet per hour under unit head.

The permeability of the refuse used in the laboratory experiments described in Chapter 4 was calculated and in Table I is compared with values given by Slichter (2).

TABLE I

	Coefficient of permeability feet per hour
Slichter's values:	
Fine sand	0·9
Medium sand	3·5
Coarse sand	13·8
Fine gravel	86·5
Experimental values:	
House refuse—	
1st experiment—beginning (Chapter 4)	7·7
end	0·6
2nd experiment (Chapter 4)	3·2

The permeability of the refuse was thus similar to that of fine to medium sand and should allow the passage of water through it in the wet pit.

The cross-sectional area of the refuse in the wet tip in the pilot-scale plant would be of the order of 250 sq. ft. and when the tip was filled the water would have to pass through a length of about 30 ft. of refuse. The amount of effluent required to feed all the filters and give a reserve was calculated to be about 30-galls. per hour, and the head required to produce this quantity under the conditions outlined, and taking the coefficient of permeability to be 3·2, was calculated to be 2·1-ins. To anticipate results the actual head found experimentally was 2·5-ins.

The pilot-scale experimental wet tip

The sedimentation tanks of a disused sewage plant at Bushey were available for these experiments. These tanks were in series and connected by a common underground drain. They were approximately 42 ft. × 35 ft. × 5 ft. deep, and adjoined on their long sides and therefore the water inflow was arranged to be on the longer side. Thus, tipping into the tip was planned to start at one edge and proceed in a transverse direction to the water flow. As a result a passage, narrowing with each successive tipping, would remain open for the flow of water whether the water permeated the refuse or not. It might have been better if it could have been arranged to build up the tip in the direction of the water flow, but the site was unsuitable for this procedure and in any case the experiment as planned followed the conditions present in many natural sites, and in fact water was shown to pass through the refuse even when the tip was incompletely filled.

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Before adaptation of the two tanks selected for these experiments the underground drains were sealed and the walls of the tanks repaired where necessary.

The lay-out can be seen on Plate 3 and is shown diagrammatically in Figure 5.1.

The tanks, A and B, were each 42 ft. long and 35 ft. wide. The walls of A, the wet tip, were raised to give a depth of 6 ft. A concrete ramp was constructed along one of the 35-ft. sides to facilitate tipping. The two tanks were connected by an orifice O, 1 ft. 6-ins. in diameter, which was situated about 3 ft. from the bottom of the wall dividing the tanks and about 9 ft. from the end opposite to the tipping ramp.

Screens G of expanded metal were fixed along each of the 42-ft. sides of tank A. This was done to contain the refuse and provide a clear water space at each end of the tank. A sparge pipe S was laid along the end of tank A to provide the inflow water to the tank, and the outlets were each fitted with a tap so that the position of entry of feed water could be selected.

Tank B, used for the filtration unit, was divided into sections by walls, 4 ft. high, to give a distribution channel D running the entire length of tank B, and at right-angles to this the 12 horizontal filters. The purpose of this channel was to provide a homogeneous effluent to feed to each of the 12 filtration compartments which abutted into the channel. These filtration compartments were arranged in three series each having lengths of 6, 12, 18 and 24 ft. to hold filter material.

At the end of the distribution channel (D.C.) a weir E was erected, its height was 3¼ ft. or 9-ins. less than the other walls in pit B. By this arrangement the level of water in the distribution channel was kept constant, and it was possible therefore to maintain a constant head between this and the outflow from each of the 12 filtration compartments. Each of the 12 filtration compartments were connected to the distribution channel by two stopcocks, one near the top and the other near the bottom of the wall of the distribution channel.

Thus water fed via the sparge pipe S into the tip in tank A would pass through it and then through the orifice O into the distribution channel D, any excess of water, not passed through the 12 horizontal filters, going over the weir the height of which determined the level of water in tank A and in the distribution channel.

Choice of filter material

The most common gravel is said to be 1½-in. ballast, and this material was therefore selected to fill one series of filters. It is a medium grade material and the filters containing it were designated M.6, M.12, M.18 and M.24, the figure denoting the length in feet of the filter. The coarse portion of the 1½-in. ballast, mainly stones was selected for the next series of four filters, C.6, C.12, C.18 and C.24, and the third series of filters were filled with the fine material of the 1½-in. ballast, F.6, F.12, F.18 and F.24. Thus there was a series of 12 filters ranging from 6 ft. of coarse material to 24 ft. of fine material.

Analyses of these three grades of gravel were made by the Building Research Station of the Department of Scientific and Industrial Research, and a summary of the results obtained is given in Table II.

FIGURE 5.1
PLAN OF WET PIT AND HORIZONTAL FILTERS.

Scale $\frac{3}{16}'' = 1'$

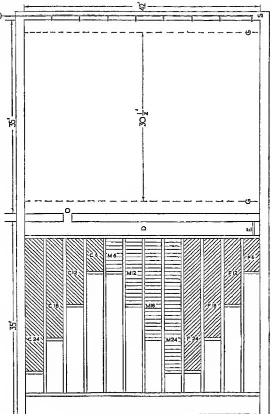


TABLE II

Percentage by weight of size of material used in the filters

Size in inches	Coarse	Medium	Fine
2 to 3	13·3	—	—
1·5 to 2	33·1	—	—
1 to 1·5	35·7	10·5	—
0·75 to 1·0	11·3	16·0	—
0·375 to 0·75	5·0	31·3	—
0·188 to 0·375	0·8	16·2	1·1
0·095 to 0·188	0·8	5·2	20·9
0·047 to 0·095	—	6·1	21·0
0·024 to 0·047	—	4·9	18·3
0·012 to 0·024	—	7·2	30·7
0·006 to 0·012	—	0·8	6·8
less than 0·006	—	—	1·2

Control and measurement of water flows

(i) *Inlet to wet tip* (*Tank A*).—The water main was connected to the sparge pipe (S) via a stopcock and a water meter. Readings of the amount of inflow water were taken each day.

(ii) *Weir outlet* (*E*) *from distribution channel* (*D*).—Effluent passing over the weir discharged into a sump from which it was pumped automatically when the level reached a predetermined height. An electrical counting device recorded the number of times the pump operated and as the volume pumped each time was constant, the total volume passing over the weir in any period could be calculated.

(iii) *Horizontal filter compartments* (C.6 to F.24).—About 4 ft. of ⅜-in. diameter plastic tubing terminating in about 1 ft. of ½-in. diameter brass tubing was connected to an outlet hole situated at the bottom of the end retaining wall of each filter compartment. The brass tubing was clamped horizontally in an adjustable stand. This tubing which was the final outlet from the filter compartment could be raised or lowered and the difference between its level and that of the water in the distribution channel gave the necessary head to control the flow through the filters. Filter effluent from the brass tube fell into a "tipping bucket" which was made of polythene and pivoted on an axis across its width near the top of the bucket. Three of its sides were vertical, but the fourth ran out at an acute angle giving the bucket a scoop-like shape. The bucket tipped when it was filled to a definite level and completely emptied itself. The volume of liquid spilled was about 1·5 litres and was constant to within one or two c.c.s., the operation lasting only a few seconds. The number of times the tipping bucket operated was electrically counted and recorded, and thus the amount of effluent coming from each filter was known.

(iv) Effluent from the weir sump was pumped to a storage tank which fed the three vertical filters and the excess was pumped to a holding tank and thence pumped to waste.

Calibration of the plant

Measurements were made to correlate the "head" with rates of flow. These measurements were made while passing clean tap water through the filter before the experiment began. It was found that to maintain a rate of flow of the order of 5 litres per hour, the coarse and medium ballast filters required a head of less than ¼-in., while the sand filters required not more than 5-ins. It proved impossible to establish the correlation exactly at these small heads, and during the actual experiment rates of flow were measured directly, the required flow being maintained by empirical adjustments to the head applied to individual filters. This proved to be ineffective with the sand filters where the inlets tended to choke, and it was necessary to restore flow conditions by regular cleaning of these holes.

Temperatures

A record was kept of the temperature of the water entering Tip A, and of the effluent leaving the tip through the connection to the distribution channel. The temperature of the refuse was determined by regular measurements with a probe thermometer at 10-in. intervals downward from fixed positions on the surface of the refuse. These positions were located in portions of the refuse tipped on different dates so that during the filling of the tip the number of positions increased from one at the beginning of the experiment to six when the tip was completely filled.

Measurement of void space in the filter material

In the first instance this was done by filling a bucket with the filter material and then adding water until it just reached the surface layer of the filter material. The volume of water required expressed as a percentage of the volume of filter material was taken to represent the void space.

In the second instance the eight filters, filled with the coarse and medium filter material, were filled with water and the volume measured. It was not practicable in the fine filters because of the time required to drain and refill these filter beds.

The results obtained are given below:

Percentage of void space

	Bucket method			Filter bed method average
Coarse material	40	C6	37	38
		C12	37	
		C18	39	
		C24	40	
Medium material ..	20	M6	17	18
		M12	20	
		M18	17	
		M24	17	
Fine material	29	—		—

1. J. F. Furness. Tipping in Wet Pits. *Municipal Journal*, 6th August, 1954, page 1811.

2. J. F. Furness. Egham continues Wet Pit Tipping Tests. *Municipal Journal*, 11th May, 1956, page 1055.

3. C. S. Slichter. Theoretical Investigations of the Motion of Groundwater. U.S. Geol. Surv. 19. Ann. Rep., Part 2, 301 (1899).

4. I. I. Chebotarew. Dynamics of Subterranean Waters. Part 1. Types of Flow. *Wat. and Wat. Engng.*, **57**, 186 (1953).

6. Disposal of House Refuse in Wet Pits

General plan of the experiment

In practice a wet tipping area may take a number of years to fill completely, and it was decided therefore that tipping in the experimental pit should be intermittent and should be controlled by consideration of the chemical condition of the water in the free area of the pit and in the distribution channel. It was further decided that this chemical condition should be judged on that obtained in natural tipping sites such as Egham, and that the pollution in the experimental pit should not be allowed to become excessive. This was deemed to be important for the amount of purification that took place in the horizontal filters would be influenced by the load put on them, and if the experiments were to be a guide to the likely condition of the effluents from wet pits as they entered the water table, conditions would have to be as close to those occurring naturally as possible.

Determinations of ammonia, permanganate value and nitrite of the effluent in the distribution channel were made at the site each day, and from each of the 12 horizontal filters about three times each week. Dissolved oxygen was also determined on the site, but more detailed analyses, including bacteriological, were carried out on samples taken by car to the Government Laboratory in London. The effluents in the distribution channel and those from the filters were examined in detail each week, but as the experiment progressed, those from the filters were examined fortnightly, half being done one week and half during the following week. These examinations, both chemical and bacteriological, were similar to those carried out on the percolate from the dry tip described in Chapter 3.

Commencement of the tipping

At the beginning of September, 1955, the pit, distribution channel and horizontal filters were filled with water supplied by the Colne Valley Water Co. and the water allowed to run to waste for several days. Two analyses of this water are given in Table I.

TABLE I

Feed water

(Supply—Colne Valley Water Co.) Sampled 11th March, 1957, and 27th March, 1957.

*p*H	7·6–7·9
Conductivity mhos./cm. cube	550–735
	parts per million
Total dissolved solids	340
Ammoniacal nitrogen	0·033
Albuminoid nitrogen	0·027
Nitrous nitrogen	0·16
Nitric nitrogen	7·1– 7·3
P.V. (four hours)	0·36
Total hardness, $CaCO_3$	230 –182
Alkalinity, $CaCO_3$	111 – 68
Calcium, $CaCO_3$	209
Magnesium, $CaCO_3$	21
Sodium	21
Chloride, Cl	30 – 29
Sulphate, SO_4	84
Silicate, SiO_2	13

The water was shut off and tipping of house refuse started on the 5th September and continued until the 9th, when about a quarter of the surface area of the pit was filled. No consolidation was attempted. The flow of water was restarted on the 10th September. The level of the refuse in the tank fell, and from time to time further additions of refuse became necessary in order to keep the surface of the refuse above water level. The last tipping to this end was on the 7th November, 1955, after which the surface of the refuse was covered with soil as is normal practice.

Subsequent tipping was arranged when indicated by the chemical condition of the effluent and the pit was filled by stages, the final tipping to fill the pit taking place on the 6th December, 1956.

The dates of tipping and the amounts of refuse tipped are given in Table II.

TABLE II

Weight of refuse tipped and date of tipping

Date of tipping	Tons	Cwts.	Qrs.	Free water* Feet from section filled*
5th to 9th September, 1955 ..	17	12	0	35·1
4th to 5th October, 1955 ..	1	16	1	34·4
25th October, 1955	2	8	0	33·8
7th November, 1955	2	10	2	32·5
2nd to 4th January, 1956 ..	37	3	0	18·0
2nd to 3rd May, 1956	7	9	0	15·1
19th to 20th June, 1956 ..	7	5	1	12·3
16th July, 1956	3	8	2	10·9
8th to 9th August, 1956 ..	6	14	3	8·3
4th to 6th December, 1956 ..	21	5	2	0
TOTAL ..	107	12	3	

* Free water space.

Width of pit = 42 ft.

Total weight of refuse, 107·6 tons, occupies whole 42 ft.

Then X tons occupies $\frac{X}{107 \cdot 6} \times 42$ ft.

and free water $= 42\left(1 - \frac{X}{107 \cdot 6}\right)$ ft.

Rates of flow through the system

The rate of flow of underground water is variable, depending on the hydraulic gradient, but the average rate is said to be of the order of 1 ft. in 24 hours. Control of the effluent from the wet tip through the horizontal filters at such a low rate would, in the absence of any blockage, require a head of less than ¼-in. In practice, however, it was found that deposits in the filter material slowed up the rate of flow necessitating readjustment of the water head. This was particularly noticeable in the case of the sand filters and at times heads of nearly 28-ins. were used in the 24-ft. filter; even in the 6-ft. filter heads of up to 19-ins. were necessary. In the coarse ballast, heads of more than 0·5-ins. were not needed, but in the medium ballast flows were sometimes difficult to maintain and heads up to 7-ins. were used. The partial blockage of the sand filters occurred at the inlets to the filters from the distribution channel and in order to restore flow conditions manual clearing of the inlet holes was carried out when necessary.

At the commencement of the experiment the inflow of water to the wet tip was of the order of 1,600-galls. per day, and that not passed through the 12 horizontal filters and the three vertical filters was run to waste. The strength of the effluent in the distribution channel not only fell more rapidly than was expected, but also it did not reach a level corresponding to that experienced in natural tipping sites. It was decided, therefore, to reduce the flow of water through the wet pit and from October, 1955, about 700-galls per day were supplied.

The rates of flow of effluent from the distribution channel through the 12 horizontal filters were kept as steady as possible having regard to the silting of the inlet pipe mentioned above. It was found impracticable to keep the rate of flow at the same level in all the filters, but an effort was made to keep a comparable rate in each series of four filters. The average rates in gallons per day passing through the filters during the investigation were as follows:

TABLE III

Average rate of flow—Gallons per day

Coarse ft.				Medium ft.				Sand ft.			
6	12	18	24	6	12	18	24	6	12	18	24
32·5	34·1	31·7	33·3	25·4	31·7	26·2	30·1	15·1	16·7	24·6	15·1

These values were maintained without much variation except during February, 1956, when icy conditions stopped the flows through the filters.

The void spaces in the filters were measured as described in Chapter 5, and taking these into account the linear flow in the filters can be calculated using the formula

$$Q = 0 \cdot 0625 \text{ K.A.V.}$$

where Q = Quantity of water discharged in gallons per day.
K = Percentage of void space.
A = Cross sectional area of filter bed in square feet.
V = Linear velocity through filter in feet per day.

These values are given in Table IV below.

TABLE IV

Average linear velocity through the filters—Feet per day

Coarse ft.				Medium ft.				Sand ft.			
6	12	18	24	6	12	18	24	6	12	18	24
1·4	1·4	1·3	1·4	2·3	2·9	2·4	2·7	0·9	0·9	1·4	0·9

These values, particularly those in the medium grade ballast, are probably somewhat higher than the average ground water flows, as a result the filters will tend to reproduce the worst conditions found in nature; it being assumed that the higher the rate of flow the lower the purification effected by filtration through gravel.

Considerable difficulty was experienced in rendering the walls of the filter beds, the wet pit and the distribution channel impervious to water. Measurements were made daily of the inlet water, rainfall falling on the pit and the filters, the effluent from the wet pit passing to waste and that passing through the horizontal filters. In dry weather there was, in fact, a loss which on average was about 4 per cent of the inlet water. This figure which must include evaporation is probably high since the measurement of water passing to waste over the weir in the distribution channel was not very satisfactory and low readings were probably recorded. In wet weather the loss was apparently greater when the calculated amount of rain falling on the system was added to the inflow water. This rather suggests that the amount of rain actually falling on the pit, distribution channel and filters was over-estimated but some of the rain falling on the refuse above water-level would have evaporated. The loss of water due to evaporation was not measured, and taking all factors into account it may be concluded that leakage was insufficient to invalidate the results of the experiment.

Permeability of the refuse

The amounts of polluting substances actually leached from the refuse are dealt with later in this Chapter, and it will be seen that these represent a fraction only of the total water-soluble material present in the refuse. It is likely, therefore, that whilst there was some flow through the refuse, the main flow of water was around the perimeter of the refuse in the wet tip and that this was the chief source of the pollution in the distribution channel throughout most of the experiment.

The wet pit was filled completely on 6th December, 1956, and in the absence of a free water path the flow was necessarily through the refuse. At the beginning of this period the head between the inlet and outlet of the pit was 0·5-in., but this built up and at the end of December a head of 1-in. was necessary to obtain a flow of 125 litres per hour. At the beginning of February, 1957, the head was 2-ins. to give a flow of 127 litres per hour; at the beginning of March the head was 2·5-ins. and the flow 131 litres per hour, and this persisted until the end of the experiment at the end of March, 1957.

The coefficients of permeability, as given by Darcy's Law (see Chapter 5), were calculated and the following values obtained:

TABLE V

Permeability of the refuse

Date	Head (inches)	Rate of flow (litres per hour)	Coefficient of permeability (cu. ft./sq. ft./ft. head per ft./hour)
14th December ..	0·5	147	28·2
28th December ..	1·0	125	12·3
14th January ..	1·25	128	10·0
1st February ..	2·0	127	6·3
27th February ..	2·5	125	4·9
21st March	2·5	110	4·3

When conditions had become stable the coefficient of permeability was 4·3, and this compares with the value of 3·2 found for the refuse used in the tank experiment (see Chapter 5), or somewhere about the value of 3·5 for medium sand.

Heat developed in the tip

The pit was filled progressively and temperature measurements were taken daily from each section of the tip. The values obtained for the temperatures above and below water level are given as four-weekly averages in Table VI.

Character of the house refuse used

The refuse was similar to that used in the dry tip experiment (Chapter 3), and was of domestic origin without industrial waste; it consisted of the entire domestic output, there being no separate collection of waste-food for pig feeding. The refuse was collected and delivered unsorted to the experimental tip at Bushey.

TABLE VI

TEMPERATURE OF REFUSE ABOVE WATER LEVEL

Mean temperatures °F. for periods of four weeks

Four weeks ending	Air	Position*					
		1	2	3	4	5	6
1955							
7th October	58	122					
4th November ..	52	127					
2nd December ..	47	132					
30th December ..	44	114					
1956							
27th January	39	63					
24th February	33	54					
23rd March	44	55					
20th April	50	66					
18th May	55	85	69	127			
15th June	59	108	73	119			
13th July	62	92	72	118	125		
10th August	63	80	68	83	86		
7th September ..	58	67	64	67	68		
5th October	58	67	63	65	66		
2nd November ..	52	63	57	59	62		
30th November ..	44	52	50	55	55		
28th December ..	44	50	46	50	50	57	60
1957							
25th January	43	44	42	44	45	49	50
22nd February	45	43	42	43	42	49	49
22nd March	49	45	44	44	46	48	48

TABLE VI—*contd.*

TEMPERATURES OF REFUSE BELOW WATER LEVEL

Mean temperatures °F. for periods of four weeks

Four weeks ending	Inlet water	Position*						Outlet effluent
		1	2	3	4	5	6	
1955								
7th October	—	96						56
4th November	53	85						46
2nd December	50	97						42
30th December	47	87						40
1956								
27th January	44	64						40
24th February	42	69						37
23rd March	43	63						40
20th April	49	64						46
18th May	55	72		98				50
15th June	58	81	68	100				56
13th July	59	83	71	97	93			58
10th August	61	74	70	89	90			62
7th September	58	67	68	77	76			58
5th October	57	65	64	71	70			59
2nd November	54	61	61	67	67			51
30th November	50	56	56	67	66			45
28th December	49	52	51	58	58	56	52	47
1957								
25th January	48	47	46	49	48	52	51	45
22nd February	48	45	44	46	45	51	49	45
22nd March	49	44	44	46	45	48	47	45

* Position 1 was in the refuse tipped 5th to 6th September, 1955.

* Position 2 was in the refuse tipped in October, 1955.

* Position 3 was in the refuse tipped 2nd to 3rd May, 1956.

* Position 4 was in the refuse tipped 19th to 20th June, 1956.

* Positions 5 and 6 were in the refuse tipped 4th to 6th December, 1956.

Its bulk composition was determined by sorting and sieving, and is given in Table VII.

TABLE VII

Percentage composition by weight of dry house refuse used to fill wet pit

Date	5th Sept. 1955	6th Sept. 1955	8th Sept. 1955	20th Jan. 1956
R.V. of property (pre-1955 basis of assessment)..	£33	£23	£12	£15
Quantity analysed in lbs.	826	723	615	202
Percentage by weight:				
(*a*) Fine dust, under $\frac{3}{8}$-in.	13	19·2	14·2	28·5
(*b*) Small cinders $\frac{3}{8}$-in. to $\frac{3}{4}$-in.	16·2	17·5	14·9	27·4
(*c*) Large cinders $\frac{3}{4}$-in. to $1\frac{1}{2}$-in.	6·7	4·5	5·8	17·7
(*d*) Vegetable and putrescible matter	15·9	20·9	23·5	
(*e*) Paper	18·1	16·1	19·3	13·2
(*f*) Metal:				
Food containers	4·8	3·8	3·9	3·6
Other containers	1·3	0·6	1·5	
Other metals	2·9	1·9	0·4	
(*g*) Rags	2·4	2·4	3·0	1·2
(*h*) Glass bottles and jars	10·5	9·3	8·0	6·2
(*i*) Bones	0·5	0·7	0·4	0·5
(*j*) Combustible debris	3·2	2·2	3·1	trace
(*k*) Incombustible debris	4·5	1·0	1·9	1·7

The higher amount of fine dust and cinders in the January collection was typical of winter conditions, and a correspondingly higher proportion of inorganic mineral salts was also to be expected.

It is extremely difficult, perhaps impossible, to get an accurate assessment of the amount of the potential pollution in house refuse. Its heterogeneous nature precludes the preparation of a representative sample and only one component, the fine dust, can be accurately sampled and analysed. This has been done, but in addition the remaining components have been sampled and even though the samples may not be completely representative, they can give some information. It is unnecessary to know the total content of, for example, carbon in refuse as a great proportion of this, in cinders and like material, will be stable and will not be a source of pollution to underground water. Paper, cardboard and rags are slow to decompose, although over the course of time they will break down and may contribute a relatively small load of pollution to water. The important source of pollution is that which can be readily leached out by water, for it is this fraction which, if it gained direct access, might affect the water table adjacent to a tip.

The components of the house refuse collected in September, 1955, and in January, 1956, were extracted with tap water and the permanganate value, ammonia and chloride contents of the extract were determined, the sulphate

content of the extract of the January collection was also determined. The values found are given in Table VIII.

TABLE VIII

Calculated water extraction of unsorted refuse

Extraction—100 grammes to 1 litre of water, or proportionally.

Permanganate value, free ammonia, chloride and sulphate extractable from refuse expressed as parts per million of the whole, and the contribution to these concentrations of the various components of the refuse.

Refuse Collected	20th September, 1955			20th January, 1956			
Refuse Component	30 mins. P.V. p.p.m. O.	Free Ammonia p.p.m. N.	Chloride p.p.m. Cl.	30 mins. P.V. p.p.m. O.	Free Ammonia p.p.m. N.	Chloride p.p.m. Cl.	Sulphate p.p.m. SO_4
(a) Fine dust ..	174	4·6	112	71·2	5·1	334	3,840
(b) Small cinder	139	17·9	63·5	57·5	5·7	123	367
(c) Large cinder	87	5·3	42·3	}			
(d) Vegetable and putrescible matter ..	395	57·2	280	} 49·5	7·1	182	168
(e) Paper ..	168	32	253	79·2	19·8	202	418
(f) Food containers ..	27·4	2·1	5·9	}			
Other containers ..	4·1	0·1	9·5	} 3·4	0·5	9	13·7
Other metals	2·0	0·1	2·0	}			
(g) Rags.. ..	32·4	4·4	25·5	6·0	1·9	8·5	34·8
(h) Glass bottles and jars ..	12·2	0·5	3·8	7·1	0·2	3·4	10
(i) Bones ..	2·5	0·4	40·3	0·7	0·2	5·3	1·2
(j) Combustible debris ..	16·3	2·7	23·1	—	—	—	—
(k) Incombustible debris ..	0·4	0·2	1·4	0·9	0·02	0·94	3·5
TOTAL IN REFUSE	1,060·3	127·5	862·3	275·5	40·5	868·2	4,856·2

It will be noted that the September collection contained a greater proportion of vegetable and putrescible material than did the January collection, and the permanganate values and ammonia were also greater.

If these two collections are taken to represent winter and summer conditions and the summer period to be between May and October, reference to Table II will show that the pit was filled with 46·7 tons of summer refuse and 60·9 tons of winter refuse. From these figures and those given in Table VIII, the average quantities of chloride, ammonia and organic matter giving a permanganate value, extractable by water, in the refuse filling the wet pit are given in Table IX: sulphate was determined once and this figure is also given.

TABLE IX

Quantity of polluting matter extracted from fresh house refuse

Refuse	Per ton	Total in pit (107·6 tons)
Permanganate value (30 mins.)	1·38 lbs. (0·62 kilos.)	148 lbs. (67 kilos.)
Chloride, Cl	1·94 lbs. (0·88 kilos.)	209 lbs. (95 kilos.)
Ammonia, N	0·18 lbs. (0·081 kilos.)	19 lbs. (8·6 kilos.)
Sulphate, SO_4	10·9 lbs. (4·94 kilos.)	—

A separate analysis was made of the fine dust component of the refuse and in addition an aqueous extract was prepared and analysed. The results obtained are given in Table X.

TABLE X

ANALYSIS OF THE FINE DUST COMPONENT OF HOUSE REFUSE

Chemical analysis

	September, 1955 per cent	January, 1956 per cent
Moisture, at 105°C.	5·8	3·9
Silicia, as SiO_2	36·5	27·1
Iron, as Fe_2O_3	8·0	9·1
Calcium, as CaO	4·7	6·6
Magnesium, as MgO	0·3	3·6
Sodium, as Na	0·2	0·4
Sulphate, as SO_3	0·9	2·0
Phosphate, as P_2O_5	0·6	0·5
Chloride, as Cl	0·3	0·6
Loss on ignition at 1,000°C. (excluding moisture)	42·1	45·6
Organic carbon	27·0	36·1
Organic nitrogen	0·74	0·60

Water-soluble constituents, expressed as a percentage of the dust

	September, 1955 per cent	January, 1956 per cent
Ammoniacal nitrogen	0·03	0·01
Albuminoid nitrogen	0·03	0·01
Permanganate value:		
3 mins.	0·07	0·02
4 hours	0·15	0·17
Organic carbon	2·3	0·05
Organic nitrogen	0·04	0·01
B.O.D.	0·20	0·21
Calcium	0·93	1·0
Magnesium	0·14	0·15
Sodium	0·14	0·17
Carbonate, CO_3	1·2	0·07
Sulphate, SO_4	0·73	1·2
Chloride, Cl	0·29	0·12
Silica, SiO_2	0·06	0·01
Total dissolved solids	5·2	2·2
*p*H	(7·0)	(6·5)

It is possible in the case of the fine dust to assess the proportion of the total constituent extracted with water and in the cases of chloride, sulphate, organic carbon and organic nitrogen, this is shown below:

TABLE XI

Per cent of total constituent in dust fraction of refuse extracted with water in the laboratory

September, 1955				January, 1956			
Cl.	SO_4	C	N	Cl	SO_4	C	N
100	60	8·5	5·4	20	50	0·14	1·6

Summer refuse with its greater proportion of vegetable and putrescible matter gave a higher rate of extraction of organic carbon and organic nitrogen, and a similar pattern is shown in Table VIII. The proportion of sulphate extracted from winter and summer refuse was of the same order, though more sulphate was actually present in the winter refuse. There appeared, however, to be a greater proportion of chloride extracted from the September than from the January refuse, bnt this is not borne out by analyses of extracts of the same dust prepared on the site where 24 per cent was extracted in September and 20 per cent in January. If it were possible to determine the proportion of chloride extractable from other components of the refuse than from the fine dust, it is likely that between 20 and 30 per cent would also be found for it will be shown later that the amount actually leached out of the wet tip and appearing in the distribution channel agreed reasonably well with that given by the short-time extraction experiments.

Although, as has been said, the important thing from the point of view of pollution of underground water is that part of the pollution in refuse which is readily extracted with water, it nevertheless is of interest to have some idea of the total amount of organic carbon and chloride contained in the refuse used. This can be obtained very approximately from the figures already given if it can be assumed that the proportions extracted by water are the same in all components of the refuse as was found for the fine dust. Also the 30 minutes permanganate value has been related to the organic carbon by approximate ratios found over many determinations. The total organic carbon and chloride contents of the refuse obtained by this method are as follows:

TABLE XII

Organic carbon and chloride content of the refuse

	In 1 ton of refuse	Total in wet tip (107·6 tons)
Permanganate value (30 mins.) ..	36·2 lbs. (16·3 kilos)	4,000 lbs. (1,800 kilos)
Organic carbon	260 lb. (117 kilos)	28,700 lbs. (12,900 kilos)
Chloride	8·9 lbs. (4 kilos)	960 lbs. (432 kilos)

The total organic carbon content of refuse used in the dry tip given in Chapter 3 and obtained by an entirely different method was 12,700 kilos per 90 tons, or 141 kilos per ton, and this is the same order as the figures given above.

CHARACTER OF THE EFFLUENT PRODUCED

Chemical

Dissolved oxygen

Before tipping commenced, the water in the pit contained 5·4 p.p.m. of dissolved oxygen, equivalent to about 60 per cent of the saturation value. Tipping commenced on 5th September, 1955, and on the following day the concentration of oxygen had fallen to 0·1 p.p.m.

Anaerobic conditions were present throughout most of the experiment. Some reoxygenation took place during three short periods between tipping, but after the pit was completely filled on 6th December, 1956, dissolved oxygen was not again found.

General chemical analysis

The effluent in the distribution channel, containing all the pollution leached from the refuse, was examined once or twice each week. The results have been averaged in periods of four weeks, and are given in Table XIII.

During periods immediately following the tipping of refuse, the strength of the effluent temporarily increased, but subsequently decreased quite rapidly. For example, during the four weeks ending 27th January, 1956, about 37 tons of refuse were tipped and the B.O.D. increased from 63 to 1,088 p.p.m. In 16 weeks this figure had dropped to 82 p.p.m. The strength of crude domestic sewage, as measured by its B.O.D., is about 400 p.p.m., and it was only immediately after tipping that figures greater than, or approaching this, were obtained. The permanganate values were lower in comparison with the B.O.D's. than would be expected in crude sewage, as also were the organic nitrogen values. The system was, as stated, anaerobic, and ammonia was not oxidised, only a questionable trace of nitrite being formed and no nitrate. Some sulphate was reduced to sulphide, but part of this was probably retained in the pit as ferrous sulphide.

A sample of the effluent was taken on the 18th March, 1957, and the Water Pollution Research Laboratory studied its absorption of oxygen in respirometers. The initial B.O.D. (five days) was 73 p.p.m., and after incubation for 28 days practically all the nitrogen originally present as ammonia and organic nitrogen was present as nitrate. The measured 28-day oxygen demand of the sample was 240 p.p.m., which was in reasonable agreement with the value of 229 p.p.m. estimated from the initial composition of the sample assuming that the oxygen demand $= 2 \cdot 67 \times$ organic carbon $+ 4 \cdot 57 \times$ ammoniacal and organic nitrogen $+ 2 \times$ sulphide content of the sample.

TABLE XIII

CHEMICAL DATA

Distribution channel: Data averaged over periods of four weeks

Four weeks ending 10 a.m. Friday	Number of samples	Refuse tipped during period	Parts per million												
			Oxygen consumed from permanganate (P.V.) at 80° F in		Bio-chemical oxygen demand (B.O.D.)	Organic carbon C	Organic nitrogen N	Free ammonia N	Album-inoid ammonia N	Nitrite N	Chloride Cl	Sulphate SO_4	Sulphide S	Turbidity (silica scale)	*p*H
		Tons	30 mins.	4 hours											
1955															
7th October.. ..	8	19·4	19·2	32·5	228	126	5·0	5·1	2·9	0	54	70	3·4	125	6·8
4th November ..	8	2·4	15·8	24·1	147	83	3·0	3·2	1·7	0·01	41	21	7·0	235	7·1
2nd December ..	8	2·5	14·0	22·8	126	74	2·5	3·4	1·6	0·01	39	21	7·0	155	7·3
30th December ..	6	—	5·9	9·1	63	43	1·4	2·1	0·8	0·03	34	38	1·4	50	7·2
1956															
27th January ..	7	37·1	84·9	148·3	1,088	597	10·7	34·6	6·9	0·05	152	369	5·3	175	6·2
24th February ..	5	—	34·2	53·8	594	318	5·7	16·3	3·2	0·42	121	274	6·2	200	6·6
23rd March	7	—	8·1	12·3	124	77	2·9	7·8	1·2	0·03	54	96	2·5	65	7·0
20th April	5	—	8·1	13·9	82	52	2·5	3·6	1·6	0·03	49	71	2·8	105	7·4
18th May	4	7·4	11·6	19·0	206	105	2·6	11·4	1·7	0·01	65	51	5·0	205	7·2
15th June	4	—	16·2	25·1	245	135	2·1	18·0	1·8	0·02	76	15	4·8	225	7·4
13th July	3	7·3	23·1	38·6	413	252	4·3	24·4	2·4	0	100	3	13·6	365	7·1
10th August ..	3	10·1	40·5	58·7	818	410	6·4	47·8	4·1	0·01	140	10	14·7	670	6·6
7th September ..	4	—	44·9	64·4	975	456	6·9	53·6	5·3	0	128	3	9·5	520	6·8
5th October ..	4	—	25·3	39·3	241	147	4·2	42·2	3·8	0	82	5	9·0	470	6·9
22nd November ..	4	—	17·6	22·5	50	60	3·2	41·0	2·1	0·01	78	27	6·8	205	7·1
30th November ..	4	—	6·0	9·3	13	19	2·4	25·5	1·6	0·12	61	53	4·3	125	7·1
28th December ..	6	21·3	32·7	49·0	365	210	9·1	102·8	7·6	0·02	216	306	9·3	270	6·8
1957															
25th January ..	5	—	15·4	22·8	233	126	3·4	90·8	2·6	0	152	50	4·8	185	6·9
22nd February ..	4	—	10·3	15·1	108	73	2·2	45·3	2·0	0	91	19	2·4	140	7·0
22nd March	4	—	8·6	13·1	74	38	2·3	30·5	1·4	0	78	5	2·6	180	7·0

Wet pit completely filled on 4th to 6th December, 1956, after which there was no free water surface exposed; passage of water through refuse was not interrupted.

Apart from sulphate and chloride, analyses of the effluent in the distribution chamber were concerned chiefly with organic pollution and its degradation products. On occasion, other determinations were carried out and the figures given in Table XIV refer to a sample drawn on 10th September, 1956. The B.O.D. at this time was of the order of 250 p.p.m.

TABLE XIV

Distribution channel—10th September, 1956

	p.p.m.
Total dissolved solids	994 dried at 180°C. 548 dried at 600°C.
Suspended solids	82
Total hardness, $CaCO_3$ ..	523
Calcium hardness, $CaCO_3$ ..	396
Magnesium hardness, $CaCO_3$ ..	127
Alkalinity, $CaCO_3$	688
Sulphate, SO_4	4
Chloride, Cl	103
Silicate, SiO_2	30
Sulphide, S	2
Ammoniacal nitrogen	47
Sodium, Na	54
Potassium, K	absent
Iron (total) Fe	6
Copper	absent
Lead	absent
*p*H value	(7·5)
Dissolved Oxygen	absent

Bacteriological

The numbers of *Coli-aerogenes*, *E. coli-I* and faecal *streptococci* were determined by the methods described in the Appendix. The maximum numbers of bacteria were obtained almost immediately after tipping of refuse, and thereafter declined. Table XV gives a summary of the results obtained.

TABLE XV

Numbers of bacteria per ml. in the distribution channel effluent

Period after tipping	Tons tipped	No. of days in period	*Coli-aerogenes* Max.	Min.	*E. coli–I* Max.	Min.	*Faecal streptococci* Max.	Min.
9th Sept. to 4th Oct., 1955	17·6	25	24,000,000–	2,400	430,000 –	150	2,400 –	0·24
5th Oct. to 25th Oct., 1955	1·8	20	4,300–	390	240 –	24	4·3 –	0·09
26th Oct. to 6th Nov., 1955	2·4	11	930–	430	24 –	2·4	absent	
8th Nov. to 1st Jan, 1956	2·5	54	2,400–	240	43 –	0·93	0·93–	absent
5th Jan. to 1st May, 1956	37·1	116	43,000–	9·3	240 –	0·4	24 –	absent
4th May to 18th June, 1956	7·5	45	9,300–	43	9·3–	1·5	4·3 –	absent
21st Jun. to 16th Jul., 1956	7·3	25	111,000–	230	930 –	23	0·93–	absent
17th Jul. to 7 Aug., 1956	3·4	21	39,000–	9,300	9,300 –	2,300	110 –	23
10th Aug. to 3rd Dec.,1956	6·7	115	93,000–	0·75	9,300 –	0·1	230 –	absent
7th Dec. to 18th Mar. 1957	21·3	101	460,000–	15	230 –	0·15	43 –	0·23

The bacterial load in the effluent from the wet tip was at its greatest after the first tipping of refuse in September, 1955. Subsequent tippings resulted in an increase of the number of bacteria, but to a much smaller extent, the largest increase being obtained from refuse collected in the summer period. It may be significant in this connection that the first tipping was into clean water, whereas subsequent tippings were into water which was already anaerobic and polluted, and which may have contained substances which limited bacterial development. There is no reason to suppose that the bacterial flora of the refuse itself varied.

The maximum numbers of bacteria were found at the beginning of each period, but the minimum, except in the case of *Coli-aerogenes*, occurred before the end of the period. *E. coli–I*, for example, decreased more rapidly and, depending on the initial load, a reduction of 90 per cent occurred in from 7 to 30 days. When in October the air temperature was 44°F. with initial loads on two occasions of 240 and 230 *E. coli–I* per ml., 25 and 30 days were required to obtain a 90 per cent reduction in numbers, whereas when, in July, the air temperature was 62°F., two initial loads of 9,300 per ml. showed a similar reduction in 16 and 20 days.

High counts of faecal *streptococci* were not obtained during the winter months and at all times were small compared with those of *E. coli–I*. They did not persist long in the effluent, and those from the first tipping in September, 1955, were reduced by more than 90 per cent in 11 days.

The bacteriological purification of the effluent from the wet tip will be discussed again when the results of filtration of the effluent through gravel is discussed.

Assessment of the pollution leached from the refuse

The concentrations of chemical constituents of the effluent in the distribution channel are given in Table XIII, and since the volume of effluent produced is also known, the actual weight of chemicals leached from the refuse (107·6 tons) can be calculated. The inflow water to the pit (cf. Table I) contained about 30 p.p.m. of chloride, as Cl, and 84 p.p.m. of sulphate as SO_4, its inorganic nitrogen content was about 7 p.p.m.; the permanganate value was small enough to be ignored. The chloride content of the inflow, however, was appreciable, and contributed about 53·6 kilos as Cl to the total found in the effluent; this must be subtracted from the total found in the distribution channel to get that actually leached from the refuse. It is impossible to make an allowance for the sulphate of the inflow water for it can be seen from Table XIII that during the summer months the concentration of sulphate in the effluent was as low as 3 p.p.m. which was well below that of the inflow water. It seems that at times when reduction of sulphate to sulphide was at its maximum, the presence or absence of sulphate in the inflow water was immaterial, but at other times the sulphate in the tap water augmented the sulphate apparently extracted from the refuse. The actual amounts of polluting matter leached from the refuse (107·6 tons) are given below, the chloride figure being corrected for that contained in the inflow water.

TABLE XVI

The quantities of polluting matter leached from house refuse in the wet tip experiment

	Kilogrammes	lb. per ton of refuse
Permanganate value:		
30 mins.	37·4	0·77
4 hours	58·6	1·2
B.O.D.	504·5	10·3
Organic carbon	278·3	5·7
Organic nitrogen	7·5	0·15
Ammoniacal nitrogen	52·7	1·1
Albuminoid nitrogen	5·0	0·10
Chloride, Cl	101·1*	2·1*
Sulphate, SO_4	124·9	2·6
Sulphide, S	10·6	0·22

* Corrected for chloride in the inflow water.

The contents of water extractable P.V., chloride and ammonia in the refuse used was given in Table IX. When these are considered with those given in Table XVI, it can be seen that whilst all the water extractable chloride appeared in the distribution channel, only 56 per cent of the P.V. (30 minutes) was found. The last tipping which completely filled the pit with refuse took place at the beginning of December, 1956, and although the concentration of P.V. had fallen to the comparatively low value of 8·6 p.p.m. by March, 1957, the total leached out was only a little more than half that which could have been expected if a measure of self-purification had not taken place in the pit itself. That active decomposition of organic matter in the pit was taking place is also illustrated by the fact that ammonia was being produced, the total found in the distribution channel being six times that extracted from the fresh refuse.

The sulphate content of the refuse, extractable by water, was approximately 4·9 Kg. per ton. So that in the pit containing 107·6 tons, the available sulphate was approximately 527 Kg. The inflow water contributed 150 Kg. of SO_4 making a total of 677 Kg. The amount actually found in the effluent was only 125 Kg., and presumably the remaining 552 Kg. were reduced to sulphide. If so, since only about 11 Kg. of sulphide S (33 Kg. as SO_4) were found in the effluent, the remainder must have been retained in the tip probably as ferrous sulphide.

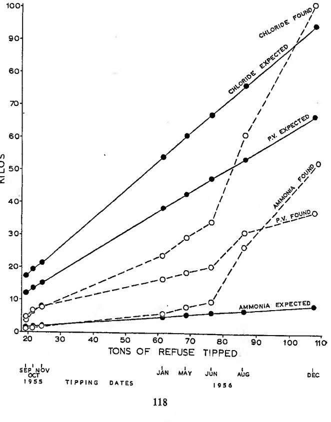
It was said earlier that until the pit was completely filled with refuse the flow of water was preferentially around the perimeter and not through the refuse. This is illustrated in Figure 6.1, which shows the estimated amounts of water extractable chloride and that actually found after each series of tipping. The "expected" values are derived from Table IX, page 111, and Table XIII, 3rd column, page 114, while the "found" values are derived from the concentrations given in Table XIII and the four-weekly flows. The two lines were divergent until the summer of 1956 and joined after the pit was completely filled and the inflowing water had to pass through rather than round the refuse. The lines for the P.V's., apart from a short period during the summer of 1956, were also divergent but in contrast to the chloride lines, did not later approach each

other. The lines for ammonia coincided until the spring of 1956, but after this period production exceeded the estimated value, a marked increase occurring in the summer of 1956 which was maintained until the end of the experiment. The system being anaerobic, ammonia was not oxidised to nitrate and the concentration of ammonia was one of the worst features of the effluent.

FIGURE 6.1

DISTRIBUTION CHANNEL

CHLORIDE, AMMONIA & P.V. QUANTITIES



Pollution remaining in the pit

At the end of the experiment drillings were made in the refuse and samples of liquor were extracted for the determination of chloride and of P.V. (30 minutes). Table XVII gives the results obtained.

TABLE XVII

	Chloride, p.p.m. Cl			P.V. 30 mins., p.p.m.
	5th March, 1957	11th March, 1957	18th March, 1957	11th March, 1957
Feed water	29	32	30	1·0
From last area tipped	206	182	172	50·0
From mid-pit ..	71	59	55	7·5
From first area tipped	40	39	39	14·5
Distribution Channel	77	78	76	12·4

It is difficult to estimate the amount of liquor in the pit since the void space within the refuse is not known. If, however, this is taken at 20 per cent the amounts of chloride and P.V., if all were flushed out, would be of the order of 3 Kg. of chloride and less than 1 Kg. of P.V., and these amounts would not materially alter the figures given in Table XVI.

Filtration of the effluent through sand and gravel

The effluent described above, from the distribution channel, was passed in parallel through 12 horizontal flow filters. The characteristics of the filter material used are described in Chapter 5, but briefly they were what is commonly known as 1½-in. ballast, said to be the most common gravel, the larger sized stones of the 1½-in. ballast and sand or the smallest sized particles of the ballast. The effluent from filters containing these three materials can, therefore, be taken as representing the worst, the average, and the best that is likely to be obtained in a natural site, and to provide a further demarcation four lengths—6, 12, 18 and 24 ft.—of each filter material were used. These filters are described for convenience as coarse filters (C), medium filters (M), fine (or sand) filters (F) and the figure following is the length in feet of the filter.

In addition to filtration through horizontal flow filters, the effluent from the distribution channel was pumped to a holding tank and thence through three vertical filters containing (1) the coarse gravel, (2) the medium and (3) the fine material or sand. These filters operated as biological filters, i.e., they were fully aerated and were used to find whether the effluent responded to normal biological treatment, and if so, what degree of purification was obtained. A depth of 6 ft. of material was used in each filter, and the rate of flow of effluent through the filter was comparable with that through the horizontal filters.

Scale of sampling and scope of examination

Sampling was spread evenly over the whole experiment; some samples were examined on the site and others taken to the Government Laboratory for more complete examination. Table XVIII gives the number of samples examined and the determinations carried out.

TABLE XVIII

FILTRATION THROUGH THE HORIZONTAL AND VERTICAL FLOW FILTERS

	Number examined on site for P.V. (30 mins.) ammonia and nitrite	Number examined in the laboratory for P.V. (30 mins. and 4 hrs.), B.O.D., Org. C., Org. N., ammonia, nitrite and nitrate, chloride, sulphate, sulphide, turbidity, and *p*H value
Effluent from Distribution Channel	373	103
Effluents from horizontal filters	2,832	630
Effluent from tank feeding vertical filters	—	35
Effluents from vertical filters	—	131

Chemical results (horizontal filters)

The average concentration of polluting matter in the effluent from each filter, and also the corresponding concentration in the effluent from the distribution channel (D.C.) for comparison are given in Table XIX.

TABLE XIX

The average concentration of polluting matter in the distribution channel and the filter effluents

Parts per million

	Site analysis		Laboratory analysis							
	P.V. (30 mins.)	NH_3–N	P.V. (30 mins.)	B.O.D.	Org. C.	Org. N.	NH_3–N	Turbidity	Cl	SO_4
D.C.	21·5	30·7	22·1	310	170	4·1	30·5	234	91	75
C.6.	17·8	30·7	17·8	274	160	3·1	26·3	156	85	47
C.12	17·3	30·8	17·1	273	158	2·8	27·9	128	88	54
C.18	16·2	30·8	16·6	289	166	3·2	31·7	116	95	65
C.24	15·6	30·8	16·2	280	159	3·1	33·3	112	101	71
M.6	14·5	30·4	14·8	223	127	2·7	31·9	109	92	43
M.12	12·9	28·2	13·0	196	116	2·5	30·9	91	91	42
M.18	11·2	25·8	10·3	172	100	2·1	25·4	102	86	37
M.24	10·0	24·5	9·5	144	90	1·9	26·2	110	86	27
F.6	9·2	26·4	8·7	120	71	1·6	27·3	172	84	46
F.12	8·8	24·0	8·2	120	73	1·6	23·4	163	82	64
F.18	6·6	21·9	6·1	96	66	1·3	20·6	177	78	50
F.24	4·5	15·5	4·1	75	51	1·2	15·5	112	74	92

It is clear that polluting matter was removed by each grade of filter material and that as the filter material decreased in size the amount of purification also increased.

This is also shown in Figure 6.2, and although some irregularities are present the general tendency of reduction of pollution with different lengths and types of filters material is clear. Figure 6.3 deals with organic nitrogen and free ammoniacal nitrogen, and illustrates a fall in the concentration of organic nitrogen. Ammonia on the other hand increased or was static in the coarse filter, but began to fall after filtration through 18 ft. of medium filter and after passing through all lengths of the sand filter. A difference between the curves for ammonia determined on the site and those determined after 24 hours in the laboratory is apparent for both the coarse and the medium filters, but not for

FIGURE 6.2

AVERAGE CONCENTRATIONS IN THE EFFLUENT FROM THE HORIZONTAL FILTER AS A PERCENTAGE OF THE AVERAGE ENTERING THE FILTER.

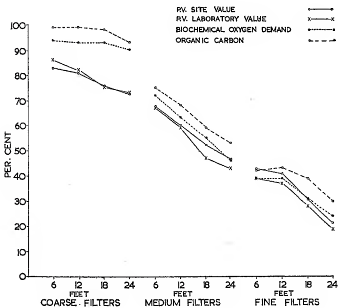
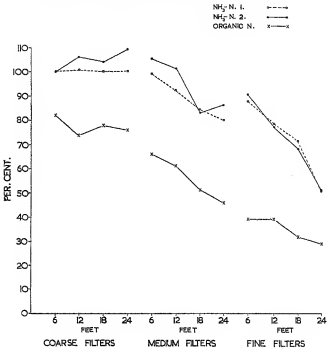


FIGURE 6.3

AVERAGE CONCENTRATIONS IN THE EFFLUENT FROM THE HORIZONTAL FILTER AS A PERCENTAGE OF THE AVERAGE ENTERING THE FILTER.

ORGANIC NITROGEN, AMMONIACAL NITROGEN, 1. DETERMINED ON SITE. 2. DETERMINED ONE DAY LATER IN LABORATORY.



the fine filters. The laboratory samples may have undergone further decomposition resulting in the production of more ammonia, whereas purification had reached a more stable phase in the fine filter and the samples did not alter appreciably after storage overnight. It will be remembered that decomposition occurring in the wet tip itself had produced ammonia and that in the anaerobic condition prevailing, oxidation to nitrite or nitrate did not take place. Dissolved oxygen was never found in the effluent from the coarse or medium filters and was only present in small amounts in F.18 and F.24 for a limited period between November, 1955, and January, 1956, thereafter it was absent. The condition in the horizontal filters was anaerobic, sulphide was present in all the effluents and

neither nitrite nor nitrate was found. The removal of ammonia after filtration cannot, therefore, have been due to its oxidation; a possible explanation is advanced later in this chapter.

The concentrations of chloride and sulphate in the effluent from the distribution channel were not very high and, in fact, were no higher than those in many waters in regular use for drinking purposes.

The hardness of the effluent in the distribution channel was determined occasionally and on one occasion that of the effluents from the horizontal filters was also determined. There was no loss of hardness on filtration so that the concentration entering the water table would be that of the effluent from the distribution channel. This, at the beginning of the experiment, was about 230 p.p.m. as $CaCO_3$, or approximately the hardness of the feed water to the wet pit. In September, 1956, the hardness of the effluent from the pit was 523 p.p.m. $CaCO_3$, and in March, 1957, it was 510 p.p.m. $CaCO_3$. The alkalinity on the latter date was 790 p.p.m. $CaCO_3$, indicating the presence of sodium or ammonium bicarbonate in the effluent.

Samples taken and analysed on 11th March, 1957, for total iron and iron in solution gave the results shown in Table XX.

TABLE XX

The iron content of the distribution channel and filter effluents

p.p.m. Fe

	Total iron	Iron in solution
D.C.	50	40
C.6	45	35
C.12	40	30
C.18	35	30
C.24	30	25
M.6	25	18
M.12	35	25
M.18	25	20
M.24	23	18
F.6	45	35
F.12	30	23
F.18	35	30
F.24	15	10

The colour of the filter material near the inlet holes of the beds was black or greyish. This colour was essentially due to ferrous sulphide and on addition of dilute hydrochloric acid, the black colour was replaced by the original light brown colour of the filter material. The loss of iron on filtration shown in Table XX above is mainly due to the formation of ferrous sulphide.

Vertical filters

The average results of filtration through the three vertical filters are given in Table XXI.

TABLE XXI

The average concentration of polluting matter in the effluents from the vertical filters

Parts per million

	P.V. (30 mins.)	B.O.D.	Org. C.	Org. N.	NH_3 N.	NO_2+ NO_3 N.	Cl	SO_4	Sul-phide S.	Tur-bidity
Inlet from distribution channel	17·9	244	146	3·2	24·1	1·2	80	56·5	6·9	221
Coarse filter effluent ..	6·8	31·4	35·8	2·5	4·6	18·8	81	72·8	0·9	31
Medium filter effluent ..	3·2	6·7	17·5	1·2	2·0	20·6	81	66·3	0·4	6
Fine filter effluent	3·6	13·2	21·2	1·3	6·9	18·1	79	54·5	0·1	14

These results are illustrated in Figure 6.4, which shows that there was little difference between the purification obtained in the medium and fine filters, each showing a reduction of at least 95 per cent of the B.O.D., the resulting effluent corresponded to that of a well purified sewage effluent. The system here in contrast to that in the horizontal filters was aerobic and oxidation of ammonia to nitrite and nitrate was nearly quantitative. This is shown in Figure 6.5 on a concentration basis. It should be noted here that although the concentration of ammonia was comparatively low, 2 p.p.m. N in the medium filter, the concentration of nitrate plus nitrite of about 21 p.p.m. was high.

PURIFICATION BY FILTRATION ON A QUANTITY BASIS

Organic matter

As stated earlier in this chapter, the rates of flow through the filters were not always constant, and this to some extent must have affected the concentrations of polluting substances in the effluents. The amounts of effluent obtained from the filters were measured, and using these figures and the concentrations found in analyses the quantities in kilogrammes of polluting substance were calculated. Chloride is not removed by filtration and slight reductions which were sometimes found were almost certainly due to dilution by rainwater falling on the horizontal filters. Dilution by rainwater would also affect the concentration of polluting substances, and consequently the calculated quantities have been adjusted by the factor necessary to get a 100 per cent return of chloride. Table XXII gives the percentage removed on a quantity basis after filtration through each filter, the figures having been corrected for dilution by rainwater.

FIGURE 6.4

AVERAGE CONCENTRATIONS OF THE EFFLUENTS FROM THE VERTICAL FILTERS AS A PERCENTAGE OF THE AVERAGE ENTERING THE FILTERS.

PERMANGANATE VALUE . ORGANIC CARBON . BIOCHEMICAL OXYGEN DEMAND.

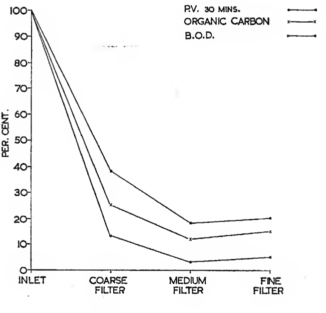


FIGURE 6.5

CHANGE IN CONCENTRATION OF ORGANIC NITROGEN, AMMONIA AND NITRITE + NITRATE AFTER FILTRATION (VERTICAL)

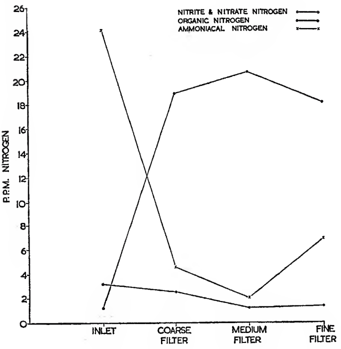


TABLE XXII

Percentage of organic matter removed by filtration

Calculated from the weights entering and leaving the filter

	P.V.	B.O.D.	Org. C	Org. N
C.6	20	15	5	25
C.12	25	15	10	30
C.18	30	15	10	30
C.24	35	25	20	30
M.6	35	30	25	35
M.12	45	35	30	40
M.18	55	40	40	45
M.24	55	50	45	50
F.6	65	55	55	60
F.12	60	50	45	55
F.18	70	65	55	60
F.24	80	75	65	60

The percentages in Table XXII represent all the results from the beginning to the end of the wet pit experiment. When these results are considered in periods dividing winter and summer conditions, no well-defined change in the mount of purification due to filtration is apparent. There are, however, indications that the filters matured during the experiment, removing greater proportions of pollution, especially that indicated by the B.O.D., as the experiment progressed. If, for example, the experiment is divided into five equal periods, the medium filters removed an average of 22 per cent of the B.O.D. during the first two periods and 53 per cent during the last three periods.

The percentage reduction of P.V., B.O.D., organic carbon and organic nitrogen, was of the same order in each of the filters. An average of these values has been taken as an index of purification of organic matter leached from refuse after filtration through three different grades of gravel. The values obtained are plotted in Figure 6.6.

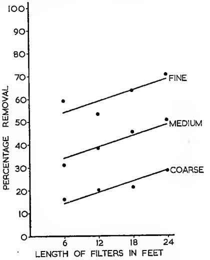
Purification was increased by approximately 5 per cent for every 6-ft. length of each grade of filter.

Inorganic matter

Determinations were made regularly of ammonia, chloride, sulphate and sulphide in the various effluents; nitrite and nitrate were not present. Chloride passed through the filters unchanged. Some sulphate was removed, but the removal was variable between the filters. Sulphide was nearly all removed, particularly in the fine filters. The amounts of sulphate and sulphide coming from the filters were influenced by the amount of reduction of sulphate to sulphide, the formation of ferrous sulphate and sulphide lost to the atmosphere. Ammonia was produced in the pit itself, and probably in the distribution channel, and the percentage removal of this ammonia when the effluent was

FIGURE 6.6

INDEX OF PURIFICATION OF ORGANIC MATTER



passed through the horizontal filters is shown in Table XXIII. The quantities have been adjusted by the factor necessary to get 100 per cent recovery of chloride in the filter effluent.

TABLE XXIII

	Percentage removal of ammoniacal nitrogen
C.6	5
C.12	0
C.18	0
C.24	0
M.6	0
M.12	0
M.18	15
M.24	5
F.6	10
F.12	15
F.18	15
F.24	40

Although neither nitrite nor nitrate was produced, ammonia was lost after filtration in M.18, M.24, and in all the fine filters. This ammonia may have been lost as nitrogen or may have been retained by a base-exchange action of the material in the filters. Both actions may have taken place.

Towards the end of the experiment 200g. samples of wet sand were taken from two positions, 4 ft. and 9 ft. from the inlet end of F.24, and were packed in glass tubes to give columns 7-ins. high by 1¼-in. diameter. The sand in the columns was washed with 2 litres of ammonia-free distilled water and then 2 litres of a 5 per cent solution of sodium chloride in ammonia-free distilled water. About 2·3 and 2·1 p.p.m. ammoniacal nitrogen were extracted by water and a further 0·9 and 1·3 p.p.m. by brine. Nitrate of the order of 6·5 and 7·9 p.p.m. N. appeared in the water extract, probably due to oxidation of some ammonia, the nature of the experiment allowing free access of air to the columns.

At the end of the wet pit experiment samples of filter material from M.18, F.18, and F.24 were extracted with water and then with a 5 per cent NaCl solution. The results are given in Table XXIV.

TABLE XXIV

Residual ammoniacal nitrogen in horizontal filter beds (fine sand and medium ballast) after beds drained and tapwater passed through for five days

To 300g. samples of fine sand and medium ballast, 300 ml. ammonia-free water added, mixture vigorously stirred allowed to stand and the ammonia determined in the supernatant liquid. Extraction with water was repeated nine times and was then followed by similar extractions with 300 mls. of a 5 per cent NaCl solution. The salt solution contained 0·08 p.p.m. NH_3–N and the results below corrected for this blank.

Sample	Extract	Extraction NH_3–N p.p.m.									Total NH_3–N extracted	
		1st	2nd	3rd	4th	5th	6th	7th	8th	9th		
18 ft. sand inlet	Water	1·00	1·17	0·83	0·33	0·58	0·67	0·42	0·67	0·46	6·13	14·52
top	Salt	3·00	1·83	0·83	0·87	0·73	0·53	0·40	0·20	—	8·39	
18 ft. sand outlet	Water	4·33	2·33	1·67	0·67	0·83	0·67	0·50	0·58	0·50	12·08	17·33
top	Salt	2·33	1·17	0·42	0·53	0·40	0·40	—	—	—	5·25	
18 ft. sand inlet	Water	1·00	0·83	0·83	0·17	0·42	0·42	0·29	0·50	0·33	4·79	9·78
bottom	Salt	3·00	1·17	0·50	0·46	0·46	0·40	—	—	—	4·99	
18 ft. sand outlet	Water	3·00	2·17	1·33	0·50	0·75	0·67	0·42	0·50	0·42	9·76	15·06
bottom	Salt	2·67	1·00	0·50	0·40	0·40	0·33	—	—	—	5·30	
24 ft. sand inlet	Water	0·33	0·67	1·00	0·33	0·42	0·58	0·47	0·58	0·58	4·96	14·63
top	Salt	3·67	1·00	1·08	1·33	1·00	0·75	0·67	0·17	—	9·67	
24 ft. sand outlet	Water	2·67	1·67	1·17	0·58	0·67	0·58	0·40	0·50	0·42	8·66	13·21
top	Salt	1·83	1·17	0·42	0·33	0·40	0·20	0·20	—	—	4·55	
24 ft. sand inlet	Water	1·17	1·00	0·87	0·33	0·33	0·33	0·23	0·42	0·13	4·81	10·47
bottom	Salt	2·00	1·67	0·50	0·40	0·46	0·33	0·20	0·10	—	5·66	
24 ft. sand outlet	Water	10·0	3·67	3·33	1·50	0·83	0·92	0·74	0·75	0·54	22·31	28·37
bottom	Salt	3·33	1·17	0·50	0·33	0·44	0·33	—	—	—	6·06	
18 ft. medium	Water	3·33	3·33	1·67	0·83	0·83	0·92	0·74	0·83	0·58	13·06	23·68
inlet bottom	Salt	5·00	2·33	0·75	0·73	0·87	0·47	0·47	—	—	10·62	
18 ft. medium	Water	1·33	1·00	0·33	0·17	0·17	0·33	0·20	0·33	0·42	4·28	9·94
outlet bottom	Salt	3·67	0·67	0·30	0·33	0·33	0·13	0·23	—	—	5·66	

It is clear from these two experiments that these filter materials possess base-exchange properties. A further experiment was carried out using other portions of the same filter material when the material was extracted by water containing nitrate. The results are given in Table XXV.

TABLE XXV

The effect of material from horizontal filter beds on a solution of nitrate

Sample	Extraction with distilled water (blank) no added NO_3 (1)				Extraction with 15 p.p.m. NO_3N solution (2)							
					Sampled after 3 days				Sampled after 7 days			
	NH_3 N	NO_2 N	NO_3 N	Total N	NH_3 N	NO_2 N	NO_3 N	Total N	NH_3 N	NO_2 N	NO_3 N	Total N
18 ft. sand inlet top ..	1·00	0·03	0·4	1·4	1·00	abs.	11·0	12·0	6·00	0·02	2·4	8·4
18 ft. sand outlet top ..	4·33	0·02	1·3	5·6	3·67	abs.	15·0	18·7	6·33	0·02	15·9	22·2
18 ft. sand inlet bottom	1·00	0·02	0·3	1·3	1·00	abs.	12·8	13·8	3·00	1·00	5·1	9·1
18 ft. sand outlet bottom	3·00	0·01	0·2	3·2	4·33	abs.	12·7	17·0	8·00	0·05	3·0	11·0
24 ft. sand inlet top ..	0·33	0·02	0·3	0·6	1·00	abs.	12·7	13·7	3·33	0·02	2·0	5·3
24 ft. sand outlet top ..	2·67	0·02	1·3	4·0	1·33	abs.	15·0	16·3	2·00	0·01	14·7	16·7
24 ft. sand inlet bottom	1·17	0·02	abs.	1·2	2·00	abs.	11·7	13·7	2·67	0·03	1·4	4·1
24 ft. sand outlet bottom	10·0	0·05	0·2	10·2	9·17	abs.	12·5	22·7	12·0	0·60	6·7	19·3
18 ft. medium inlet bottom	3·33	0·02	0·2	3·5	4·33	abs.	15·8	20·1	7·33	0·02	2·5	9·8
18 ft. medium outlet bottom	1·33	0·01	0·2	1·5	2·33	abs.	11·7	14·0	3·00	0·02	11·4	14·4

(1) 300g. filter bed material mixed with 300 ml. ammonia-free water, vigorously stirred and allowed to settle.

(2) 300g. filter bed material mixed with 300 ml. ammonia-free water containing 15 p.p.m. NO_3 as N, vigorously stirred, allowed to stand and samples of supernatant liquid decanted for analysis after three and seven days. Samples centrifuged prior to analysis.

Note.—Analysis of Colne Valley Water gave 7 p.p.m. NO_3N. No nitrate detected during main experiment in effluent from filters.

Table XXV shows a loss of nitrate and a gain of ammonia, but they do not compensate each other and overall there is a loss of nitrogen ranging from 2 to 12 p.p.m. N. This explains the fate of the nitrate in the inflow water which was not found in the effluents from the filters. Conditions in the system were such that nitrate was reduced to ammonia, and overall in the filters nitrogen was lost.

Pollution remaining in the horizontal filter beds

At the end of the experiment the filter beds were drained slowly over a period of three days. They were left empty for another two days during which time the distribution channel was isolated from the wet pit, pumped dry and cleaned out. After this the distribution channel and four of the filter beds were filled with tap water and left overnight. The filters were then run with water at measured rates and composite samples of the effluent were analysed. The results are given in Table XXVI.

TABLE XXVI

Results of washing the horizontal filter beds with tapwater 26th March, 1957, to 1st April, 1957 composite samples

Filter bed and total flow	Hours from start	P.V. 30 mins.	P.V. 4 hrs.	B.O.D.	Org. C.	Org. N.	Free ammonia N.	Nitrite N.	Nitrate N.	Chloride Cl.	Sulphate SO_4
F.18: 1,040 litres	0–5	3·8	6·1	9	8	1·1	37·1	0	0·47	87	17
	24–29	3·91	6·3	4	16	1·7	35·0	0·40	0·13	53	165
	48–53	2·81	4·8	5	14	1·2	33·6	0·24	1·60	46	189
	72–77	2·9	4·8	4	10	1·2	30·8	0·20	1·50	44	217
	144–149	2·2	3·3	4	8	1·2	29·4	0·10	1·10	38	203
F.24: 1,056 litres	0–5	3·5	6·5	11	4	1·1	58·8	0	0·53	76	17
	24–29	3·2	5·2	4	34	1·8	54·6	0·10	0·23	73	67
	48–53	2·8	4·4	5	16	1·1	58·8	0·12	1·50	59	116
	72–77	2·31	3·8	4	8	0·9	49·0	0·12	2·20	54	132
	144–149	1·5	2·6	2	10	0·9	46·2	0·04	1·90	44	113
M.18: 1,103 litres	0–5	3·5	5·9	5	6	1·5	30·1	0·25	0·68	45	300
	24–29	2·21	3·81	4	14	1·5	18·9	0·20	0·27	33	290
	48–53	1·71	3·1	4	36	1·1	22·4	0	0·20	34	310
	72–77	2·2	4·41	4	16	1·4	25·2	0	0·20	32	306
	144–149	1·0	2·9	5	12	1·1	18·2	0·06	0·14	30	266
C.18: 1,217 litres	0–5	7·3	9·3	8	12	1·3	4·0	0·25	0·28	25	140
	24–29	4·1	5·31	4	4	1·3	6·0	0·60	1·00	28	175
	48–53	2·4	3·3	3	24	1·2	4·7	0·24	0·35	29	154
	72–77	2·0	3·41	4	10	1·3	6·0	0	0·13	28	169
	144–149	1·1	2·5	5	12	1·3	4·7	0	0·27	29	161

Unfortunately time did not permit the complete washing-out of the filters. The chloride (Cl) content of the feed water was 30 p.p.m. and this value was not reached in F.18 or F.24 although it was approached. In M.18 and C.18 the wash-out, judging by the chloride, was complete, and it is clear that the amount of organic polluting matter being removed is sufficiently small to be unimportant in underground water. The organic pollution leached from F.18 and F.24 was of the same order and would not markedly affect the water table.

Dissolved oxygen was not found at all in the effluents from M.18, C.18 and F.18, but after 24 hours concentrations varying from 0·4 to 0·9 p.p.m. were found in the effluent from F.24. Both F.18 and F.24 produced a little more nitrate than did M.18 and C.18, but in no case was there real evidence of nitrification of ammonia.

At the end of the run of effluent from the wet tip through the filters the effluents contained the following concentrations of ammonia, the figure in brackets being the highest recorded figure obtained after the pit was completely filled with refuse.

Units p.p.m. N

C.18	M.18	F.18	F.24
37 (144)	37 (89)	42 (93)	43 (50)

These figures indicate that whilst ammonia was decreasing in the effluents from C.18, M.18, and more slowly in F.18, accumulated ammonia was being washed from F.24, and the process was by no means finished. In actual quantities, however, the concentrations given in Table XXIV are small, those for F.24 being about 0·05 Kg.

Summary of the amounts of pollution from refuse

Table IX gave the estimated amounts, based on laboratory work, of the P.V., chloride and ammonia that could be extracted by water from house refuse, and Table XVI gave the total amounts of polluting matter that were actually extracted during the entire experiment. The purification of the effluent by filtration has been discussed and an organic purification index was derived and shown in Figure 6.6.

It is unlikely in practice that tipping of refuse into a wet pit would be allowed or done if the pit was adjacent to a point where the water was abstracted for domestic use. Thus much more than a length of 24 ft. of filter material would be available for purification of the effluent from the pit and the degree of purification would then be higher than that actually found in the experimental work. It will be remembered that filtration through the medium or fine vertical filters removed 95 per cent of the B.O.D. and that ammonia was quantitatively oxidised to nitrate. The essential difference between the horizontal and the vertical filters was the presence of oxygen in the latter and its absence in the former. Now the water in the pit before tipping and in the water table will be oxygenated and this oxygen will play its part in the purification of the effluent as it moves away with increasing dilution from the vicinity of the wet pit.

It is reasonable, therefore, to expect that the extent of purification would at least be equivalent to that obtained in F.24, but provided a mile or more of filtration was available it might easily reach that given by the medium vertical filter. Table XXVII gives a forecast, based on the experimental work, of the

TABLE XXVII

Quantities in kilogrammes

	P.V.		B.O.D.	Org. C.	Org. N.	NH_3 N.	NO_2+ NO_3 N.	Chloride Cl.	Sulphate SO_4	Sulphide S
	30 mins.	4 hrs.								
Total extractable by water (Table IX)..	62	—	—	—	—	8·1	—	88	490†	—
Total actually found in distribution channel (Table XVI corrected to 100 tons refuse) ..	35	54	468	258	7	37*	abs.	95	116	10
M.24	18	28	239	132	4	35	abs.	95	62	
F.24	11	16	140	77	2	21	abs.	95	62	trace to 0·2
Vertical Medium ..	6	10	13	31	3	3	about 30‡	95	62	

* Actually 49 Kg. of ammonia was found but the tap water contributed about 12 Kg. of nitrate N which was lost, and may be considered to have been reduced to ammonia.

† There was 150 Kg. SO_4 in the tap water used as well as that derived from the refuse.

‡ This figure is an approximation only, more nitrogen might be lost and the value given may be high.

pollution that might affect underground water from the tipping of 100 tons of refuse in a pit containing natural ground water. Although, as was said, it is reasonable to anticipate an effect at least equal to that given by 24 ft. of fine material in an anaerobic system, or even that of 6 ft. of medium material in an aerobic system, the table includes the purification that might be expected if only a 24-ft. length of medium material was available.

The B.O.D. of an average crude domestic sewage is about 400 p.p.m. and the average volume produced is about 30-galls. per head per day. From these figures the average weight of oxygen taken up by the sewage of one person is 0·12-lb. per day or 20 Kg. per year. The amount of refuse produced is about 5 cwt. per person per year and 100 tons of refuse therefore corresponds to the collection from 400 people for one year. The calculated total B.O.D. drainage from refuse is thus $\frac{468}{400}$ or 1·17 Kg. per year per person.

From these considerations a comparison between the strengths of the pollution from refuse and from sewage can be made. This is given in Table XXVIII.

TABLE XXVIII

Percolate per year from 1,000 people (250 tons of house refuse) is equivalent to:

	Sewage of B.O.D. 400	Effluent of B.O.D. 20
	from	from
M.24	30 people	600 people
F.24	18 people	360 people
Vertical, medium ..	3 people	60 people

This, of course, does not give the complete picture. Chloride, sulphate and hardness salts will be reduced only by the dilution given by the ground water, but as the initial concentrations, particularly of chloride and sulphate, are not excessive, these should not cause undue anxiety. The fate of ammonia is another question, the concentrations are high in the percolate and if the ammonia is oxidised to nitrate the corresponding concentration would be high for domestic use unless a considerable amount of dilution took place before abstraction for this purpose.

FILTRATION THROUGH HORIZONTAL AND VERTICAL FLOW FILTERS

Bacteriological results

The bacteriological quality of the effluent from the distribution channel was described earlier in this chapter, and the effect of filtration through the coarse, medium and fine horizontal and vertical filters will now be considered.

Horizontal flow filters

The detailed results are given in the Appendix, and it will be apparent that filtration, particularly through the fine material reduced the bacterial counts. In order to obtain a more direct comparison between the action of the three

different filter materials, the results have been rearranged to show the frequencies of occurrence of different orders of counts. Thus, for example, the number of times a count of between 1 and 10 per ml. was found in the distribution channel and in each of the 12 filter effluents was extracted. Examination of the effluent from the distribution channel was made at least every week, whereas effluents from the filters were examined sometimes only on alternative weeks. The frequency figures are expressed, therefore, as percentages of the total number of weeks in which examinations were made. Table XXIX gives the percentage frequencies for *coli-aerogenes* bacteria.

TABLE XXIX

Coli-aerogenes: Percentage frequency

Ranges of counts per ml.	D.C.	C.6	C.12	C.18	C.24	M.6	M.12	M.18	M.24	F.6	F.12	F.18	F.24
0	0	0	0	0	0	2	2	5	0	7	0	11	67
0·01–0·1	0	0	2	2	0	0	2	2	5	11	35	28	11
0·1 –1·0	3	5	2	12	20	9	9	19	30	29	22	16	9
1·0 –10	11	20	22	22	10	19	19	23	16	31	16	18	9
10 –10^2	25	20	17	35	39	23	30	31	28	13	13	25	2
10^2 –10^3	29	29	33	20	17	28	19	9	9	2	7	0	0
10^3 –10^4	19	20	17	5	7	12	12	9	7	7	7	2	0
10^4 –10^5	8	5	5	2	2	5	7	2	5	0	0	0	2
10^5 –10^6	4	1	0	2	2	2	0	0	0	0	0	0	0
10^6 –10^7	1	0	2	0	2	0	0	0	0	0	0	0	0

It will be noted that there was a displacement of the peaks towards the lower counts ranges progressively from the distribution channel to F.24.

If it can be assumed that a reasonable standard for the *coli-aerogenes* organisms is the range between 0 to 1·0 per ml., a clearer picture can be obtained of the effectiveness of filtration through the horizontal filters. The percentage frequencies are given in Table XXX.

TABLE XXX

Percentage frequency of occurrence of counts of coli-aerogenes between 0 and 1·0 per ml.

Distribution channel 3 per cent

	6 ft.	12 ft.	18 ft.	24 ft.
Coarse filters ..	5	4	14	20
Medium filters ..	11	13	26	35
Fine filters	47	57	55	87

The *coli-aerogenes* group of bacteria includes many organisms of non-animal origin of questionable importance in the assessment of water quality, and this is specially true in the effluents from house refuse as it was difficult to be sure that only these organisms grew and developed under the conditions of the test. A better index is given by the counts of *E. coli–I*, for it is reasonably certain that here the growth of other bacteria was inhibited.

Table XXXI gives the percentage frequencies of the occurrence of *E. coli*, in each of the effluents.

TABLE XXXI

E. coli—Percentage frequencies

Ranges of counts, per ml.	D.C.	C.6	C.12	C.18	C.24	M.6	M.12	M.18	M.24	F.6	F.12	F.18	F.24
0	0	2	5	2	7	4	4	24	24	39	53	77	98
0·01–0·1	7	13	10	18	13	11	13	21	22	25	18	9	2
0·1 –1·0	19	25	25	35	35	18	25	24	24	20	16	9	0
1·0 –10	33	25	32	23	25	34	29	22	14	9	11	5	0
10 -10^2	19	18	13	10	10	20	21	2	7	7	2	0	0
10^2 -10^3	13	13	8	10	8	9	4	7	7	0	0	0	0
10^3 -10^4	8	2	5	0	2	4	4	0	2	0	0	0	0
10^4 -10^5	1	2	2	2	0	0	0	0	0	0	0	0	0

As was the case for the *coli-aerogenes* bacteria the peak occurrence of *E. coli–I*, moved to the lower ranges of counts from the distribution channel to F.24.

A standard can also be taken here, but it should be higher in the case of these bacteria as they are the true criteria of unwanted pollution in a water. If it is assumed that a greater colony density than 0·1 per ml. should not reach an underground water supply, the following table shows the percentage frequencies.

TABLE XXXII

Percentage frequency of occurrence of counts of E. coli–I, between 0 and 0·1 per ml.

Distribution channel 7 per cent

	6 ft.	12 ft.	18 ft.	24 ft.
Coarse filters ..	15	15	20	20
Medium filters ..	15	17	45	46
Fine filters	64	71	86	100

E. coli–I was rarely found in F.24 and when it was present the counts were less than 10 per 100 ml. Table XXXII indicates the rapid removal of these bacteria, particularly in the fine filters, and it is unlikely that they would reach underground waters in significant numbers from a natural wet pit filled with refuse.

Faecal *streptococci* were also developed and counted, and Table XXXIII gives in the same way the percentage frequency of occurrence.

TABLE XXXIII

Faecal streptococci—Percentage frequencies

Ranges of counts, per ml.	D.C.	C.6	C.12	C.18	C.24	M.6	M.12	M.18	M.24	F.6	F.12	F.18	F.24
0	40	47	59	63	62	44	44	64	62	75	86	91	100
0·01–0·1	8	17	12	7	24	18	18	20	13	16	7	7	0
0·1 –1·0	24	12	10	20	2	13	20	7	18	9	7	2	0
1·0 –10	14	17	12	3	10	18	16	9	7	0	0	0	0
10 -10^2	11	7	5	7	2	7	2	0	0	0	0	0	0
10^2 -10^3	3	0	2	0	0	0	0	0	0	0	0	0	0

Faecal *streptococci* occurred less frequently than did *E. coli-I*, and was often absent in the effluent from the distribution channel. It was never found in the effluent from F.24 and not often in F.18. Its distribution confirms the conclusion reached for *E. coli-I*, that pollution of underground waters with bacteria of faecal origin from refuse is unlikely to occur.

Vertical flow filters

The bacterial counts of the effluents from the vertical flow filters are dealt with in the same way as those from the horizontal filters. The percentage frequency of occurrence of different ranges of count are given in Table XXXIV.

TABLE XXXIV

B. coli-aerogenes group: E. coli-I: Faecal streptococci—Percentage frequencies

Organism	Range of counts No. per ml.	D.C.	Coarse	Medium	Fine
B. Coli-aerogenes group	0	0	0	13	20
	0·01– 0·10	0	8	10	20
	0·1 – 1·0	3	13	29	26
	1·0 –10	11	31	21	15
	10 -10^2	25	28	16	8
	10^2 -10^3	29	10	8	8
	10^3 -10^4	19	8	3	3
	10^4 -10^5	8	0	0	0
	10^5 -10^6	4	2	0	0
	10^6 -10^7	1	0	0	0
E. coli-I.	0	0	25	45	63
	0·01– 0·1	7	10	29	21
	0·1 – 1·0	19	18	10	10
	1·0 –10	33	23	10	3
	10 -10^2	19	15	3	0
	10^2 -10^3	13	3	3	3
	10^3 -10^4	8	3	0	0
	10^4 -10^5	1	3	0	0
Faecal *streptococci*	0	40	43	69	75
	0·01– 0·1	8	10	15	10
	0·1 – 1·0	24	26	13	15
	1·0 –10	14	15	3	0
	10 -10^2	11	3	0	0
	10^2 -10^3	3	3	0	0

The bacterial purification effected in the three vertical filters was greater than those in the horizontal filters of similar lengths. A comparison is given below in Table XXXV for the 6-ft. lengths of horizontal filters and the vertical filters.

TABLE XXXV

Organism	Filter	Range No. per ml.	Filters		
			Coarse	Medium	Fine
B. coli-aerogenes	Horizontal	0–1·0	5	11	47
B. coli-aerogenes	Vertical	0–1·0	21	52	66
E. coli–I	Horizontal	0–0·1	15	15	64
E. coli–I	Vertical	0–0·1	35	74	84

Sulphate-reducing bacteria

Samples were taken during December, 1955, and April, 1957, of the filter material in M.12, M.18 and in F.18 and F.24. Some of these samples were collected from the bottom of the filter bed by means of a probe and included filter material and liquor. Other samples were collected from the top and bottom of each end of the filter. All these samples were found to contain sulphate-reducing bacteria.

Methods used in the bacteriological examination of the percolate from the dry tip at Bushey, and the laboratory pipe experiments

(1) *Colony counts.*—Counts were made of the number of colonies growing on the following media after inoculating with the percolate and incubating for the times stated.

(*a*) MacConkey agar at 37°C. for 24 hours for the *coli-aerogenes* group of bacteria.

(*b*) MacConkey agar at 43·5°C. to 44°C. for 24 hours for *Escherichia coli-I.*

(*c*) Nutrient azide agar at 45°C. for 48 hours for *Streptococcus faecalis.*

(2) The composition of the media used for the colony counts was as follows:

MacConkey agar pH 7·4	Peptone	20g.
	Bile salt	1·5g.
	Lactose	5g.
	Sodium chloride ..	5g.
	Agar (New Zealand) ..	20g.
	Neutral red	10 mls of 0·6 per cent solution.
	Water	1 litre.
Sodium azide agar pH 6·8	Yeastrel	3g.
	Glucose	5g.
	Sodium chloride ..	5g.
	Dipotassium hydrogen phosphate	5g.
	Potassium dihydrogen phosphate	2g.
	Peptone	10g.
	Sodium azide ..	0·4g.
	Agar (New Zealand) ..	20g.
	Water	1 litre.

(3) *Procedure.*—The roll tube technique adopted consisted of inoculating 5 ml. of sterilised melted agar media in an Astell bottle with the percolate or its dilution. The bottles were plugged with rubber stoppers, the contents thoroughly mixed, and placed on revolving horizontal rollers in a bath of cold water so that the medium was rapidly solidified as a uniform thin film around the sides of the bottle. After incubation, the colonies on the agar film in the bottle were counted in a special apparatus in which the holder for the Astell bottle could be simultaneously revolved about a vertical axis and raised vertically by suitable gearing operated by an electric motor. The bottle was illuminated and a portion of the agar film viewed on a ground glass screen. When the bottle was simultaneously rotated and lifted, the images of the colonies passed across the screen and could be counted with ease and accuracy.

(4) *Confirmatory tests*.—(1) To confirm the presence of *E. coli–I* among the colonies growing on the MacConkey agar at 44°C., four colonies resembling *E. coli–I* were picked off and inoculated into peptone water. After incubation at 37°C. for four to six hours, or until turbidity indicated satisfactory growth, the culture was inoculated into peptone water and brilliant green bile broth and incubated at 44°C. for 24 hours. Production of indole in peptone water and gas production in brilliant green bile confirmed the presence of *E. coli–I*. The presence or absence of other members of the *coliform-aerogenes* group was determined by differential tests.

In addition 50 ml., 10 ml., 1 m.l. and 0·1 ml. volumes of percolate were inoculated into MacConkey broth and incubated at 37°C. for 24 hours. Tubes showing the production of acid and gas were streaked on to MacConkey agar and the colonies developed on incubation at 37°C. for 24 hours were typed by differential tests. The composition of the MacConkey broth was as follows:

(*a*) MacConkey broth—*p*H 7·4:

Peptone	20g
Bile salt	1·5g.
Lactose	5g.
Sodium chloride	5g.
Bromo-cresol purple	3·4 ml. of 1 per cent solution.
Water	1 litre.

(*b*) The composition of the media used in the differential tests was that recommended in Reports on Public Health and Medical Subjects No. 71 "The Bacteriological Examination of Water Supplies", H.M.S.O.

(2) Confirmation of the presence of *Streptococcus faecalis* among the colonies growing on the nutrient azide agar medium at 45°C. was obtained by picking off from the roll tubes, four colonies typical in appearance to faecal *streptococci*, seeding them into glucose-azide broth and incubating at 45°C. for 24 hours. The production of acidity in this medium and the presence of *streptococci* on microscopical examination was regarded as adequate confirmation of the presence of *Streptococcus faecalis*.

The composition of the medium was as follows:

Sodium azide broth for *streptococci*—*p*H 6·8:

Yeastrel	3g.
Glucose	5g.
Sodium chloride	5g.
Dipotassium hydrogen phosphate	5g.
Potassium dihydrogen phosphate	2g.
Peptone	10g.
Sodium azide	0·4g.
Bromo-cresol purple	3·4 ml. of 1 per cent solution
Water	1 litre.

(5) *Counts by the dilution method.*—The liquid medium used for determining the most probable number of coliform organisms and of *E. coli–I* was MacConkey broth of the same composition as that given above. Three tubes of broth at successive dilutions of the percolate were taken and the M.P.N. calculated from tables.

The liquid medium for the determination of the M.P.N. of *Streptococcus faecalis* by the dilution method was that given above (paragraph 4). Tubes showing acidity after incubation for two days at 45°C. were subcultured into MacConkey broth and incubated for two days at 37°C. The production of acid without gas and the presence of cocci on microscopical examination indicated the presence of *Streptococcus faecalis*.

Methods used in the bacteriological examination of the effluents from the wet tip at Bushey, and the laboratory tank experiments

(1) *Colony counts.*—Counts were made of the number of colonies growing on the following media after inoculating with the effluents and incubating for the times stated.

(*a*) MacConkey agar at 37°C. for 24 hours for the *coli-aerogenes* group.

(*b*) Sodium azide agar at 45°C. for 48 hours for *Streptococcus faecalis*.

(2) *Most probable number (M.P.N.) by the dilution method*

(*a*) *Coliform-aerogenes* group.—According to the condition of the effluents, measured volumes of suitable dilutions were inoculated into three tubes of MacConkey broth and incubated at 37°C. for 24 hours.

(*b*) *E. coli–I.*—The tubes of MacConkey broth from the coliform examination which showed the production of acid and gas were subcultured into one tube of brilliant green bile broth and one tube of peptone and incubated at 44°C. for 24 hours. The M.P.N. of *E. coli* was based on the number of tubes showing the production of gas in the brilliant green bile broth and indole in the peptone water. Confirmation of the presence of *E. coli–I* was obtained by sub-culture into differential media.

(*c*) *Streptococcus faecalis.*—Measured volumes of suitable dilutions of the effluents were inoculated into three tubes of glucose phosphate azide broth. Those tubes showing presence of acid were subcultured into MacConkey broth and incubated at 37°C. for 48 hours. The M.P.N. of *Streptococcus faecalis* was calculated from the number of tubes showing the production of acidity and the absence of gas. Confirmation was based on microscopical examination.

(3) The composition of the media was the same as that used for the examination of the percolate from the dry pit except that the bile salt in the MacConkey broth was increased to 2·5g. per litre.

Methods used in the chemical examination of the percolates and effluents from the wet and dry tips

The procedure used in the following determinations was that described in "Methods of Chemical Analysis as applied to Sewage and Sewage Effluents", H.M.S.O., London, 1956: clarity, odour, colour, ammoniacal and albuminoid nitrogen, nitrate and nitrite nitrogen, organic nitrogen, permanganate value at four hours, permanganate value at 30 minutes (method as described for three minutes), biochemical oxygen demand (Rideal-Stewart modification), organic carbon and *p*H (using *p*H meter and glass electrode).

Sulphate ..	Determined by the gravimetric method given in "Standard Methods for the examination of Water, Sewage and Industrial Wastes", 10th edition American Public Health Association Inc., New York, 1955.
Sulphide ..	Determined by the method given in "Standard Methods of Chemical Analysis", by W. D. Scott, 5th edition, D. Van Nostrand Company, Inc., New York.
Turbidity ..	Determined by measurement of the absorption in an "Eel" photoelectric absorptiometer using neutral filters. Absorptiometer calibrated with a suspension of Fuller's earth.

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PLATE 1. Dry pit at the commencement of tipping showing the clinker bed.

PLATE 2. Dry pit showing growth of grass on the surface.

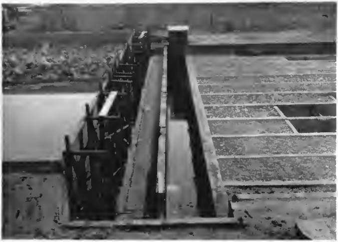

PLATE 3. Wet pit experiment showing the distribution channel between the wet pit and the horizontal filters.

PLATE 4. Wet pit experiment; close-up of the refuse used.

PLATE 5. Wet pit experiment; the horizontal filters showing the tipping buckets for measuring flows.

PLATE 6. General view of the experiment including both wet and dry pits.

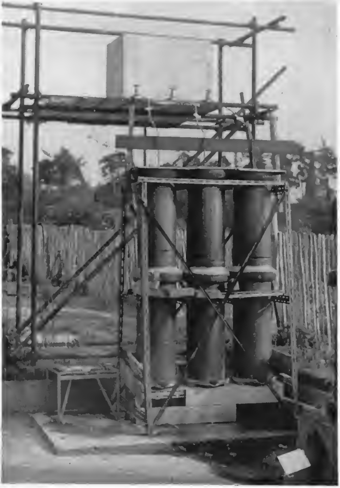

PLATE 7. Wet pit; the vertical filters.